# Space Telescope

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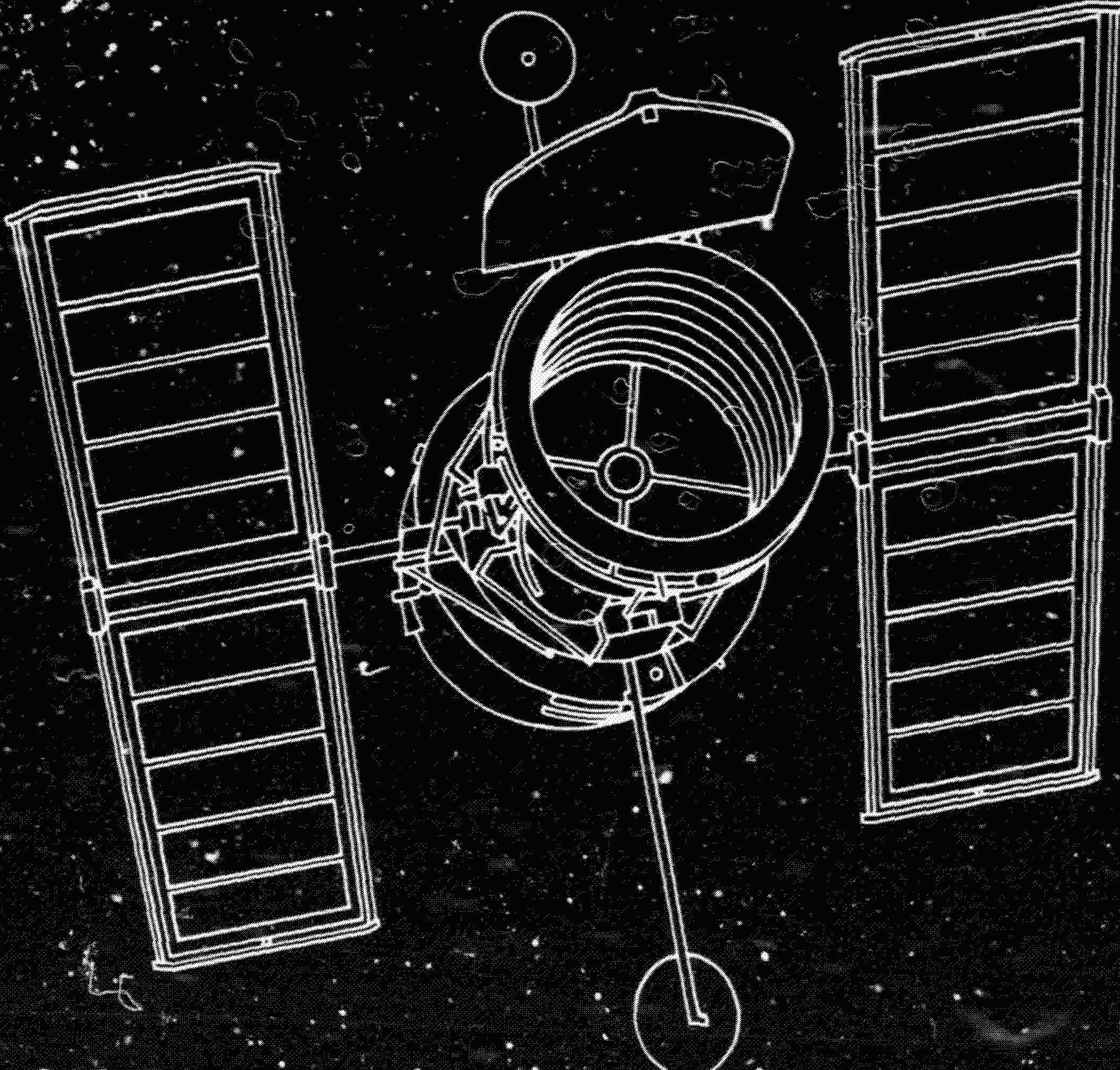

NASA

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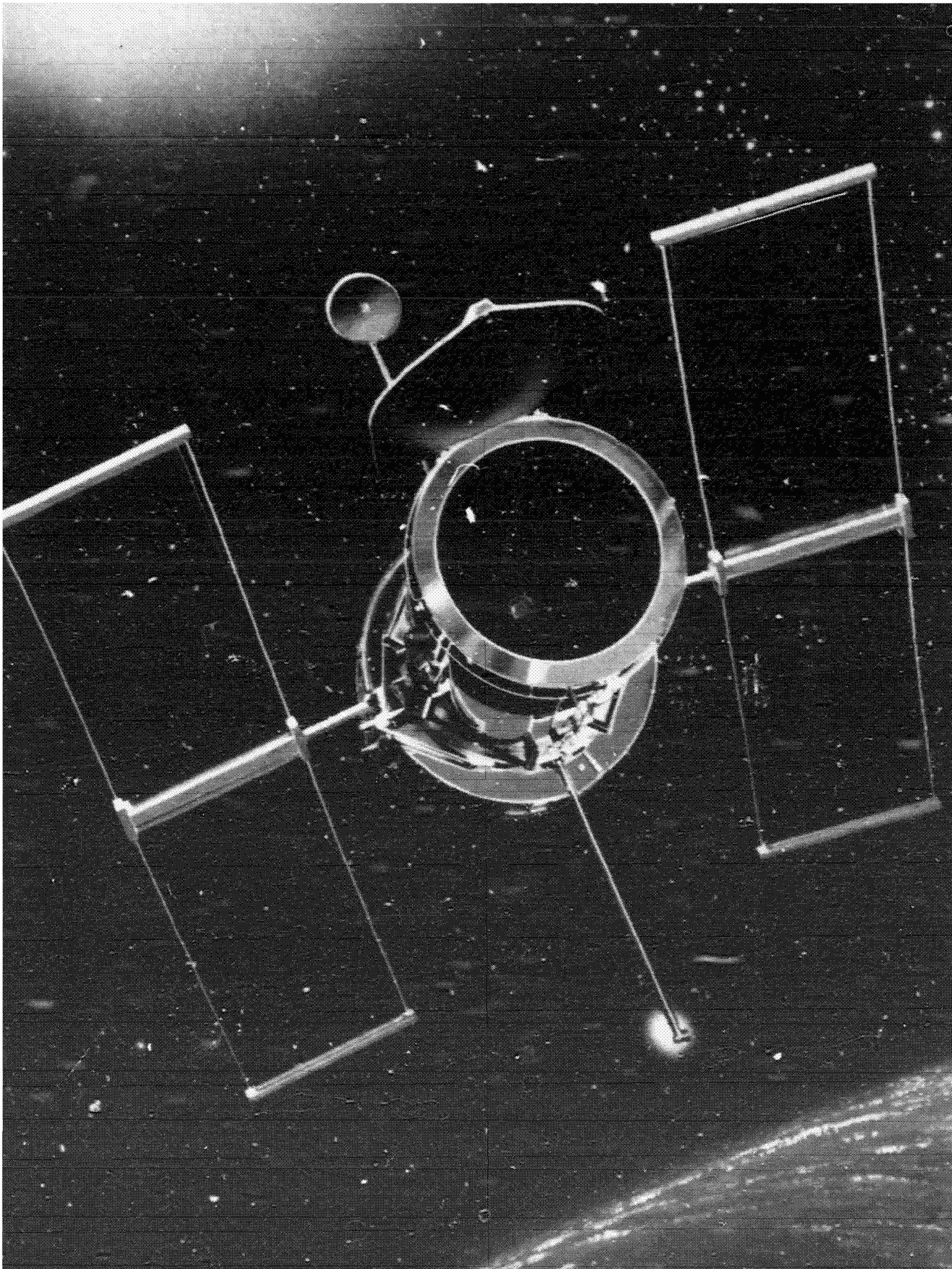
*Astronomical studies have laid the whole broad scientific/technical basis for our modern civilization. The development of mathematics is intimately tied in with efforts to understand planetary motions. The development of physics began with gravitation, and astronomy was at the heart of that discovery... Because astronomy is so basic, it is impossible to predict what benefits will flow from future astronomical discoveries. There is no doubt, however, that astronomy will maintain its role as a fundamental driver of our technological civilization. This is because the objects currently being discovered in space, are so fantastic in their character. We may be seeing totally new aspects of nature, and eventually we will turn these aspects to our advantage—we always do.*

*Dr. Noel Hinners, NASA Associate Administrator for Space Science February 1977*



*There is good reason to believe that the Space Telescope, to be launched in 1985, will be the most important scientific instrument ever flown.*

*James M. Beggs, NASA Administrator February 1982*



# *Space Telescope*

*Joseph J. McRoberts*

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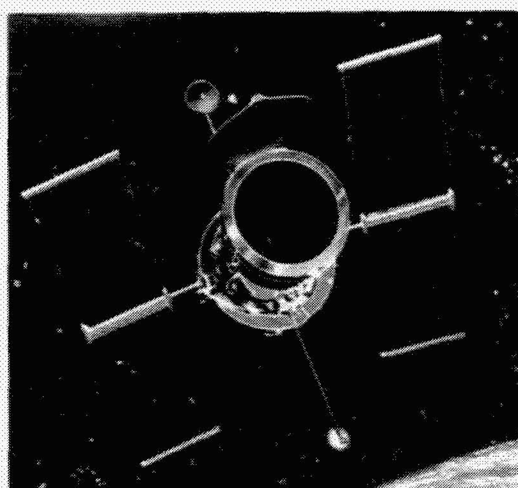
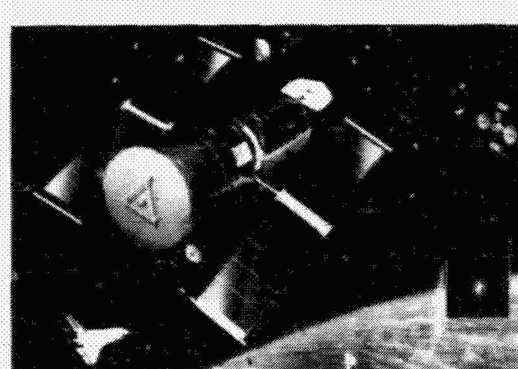
# *Contents*



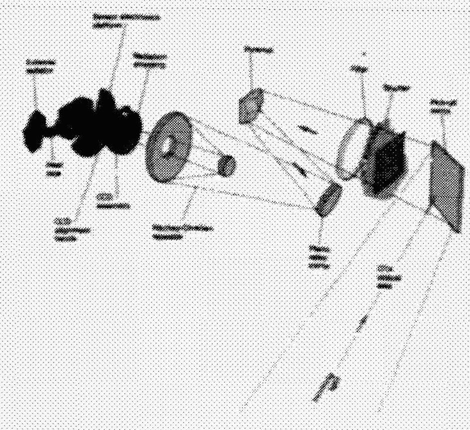


**Introduction ........................ 7**
Distortion Eliminated
Study Star Development
New Knowledge Changes Concepts and Theories
Seek Origin of the Universe
Back to the Beginning

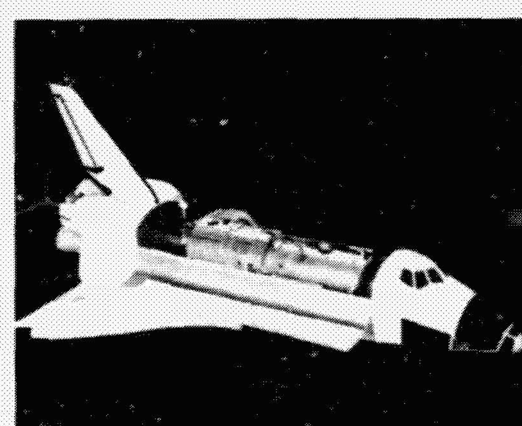
**Space Telescope Background ........ 13**
Scientists Support Telescope Concepts



**The Spacecraft ..................... 15**
Imagery Radioed to Earth
Modules Are Replaceable
Precise Pointing Planned



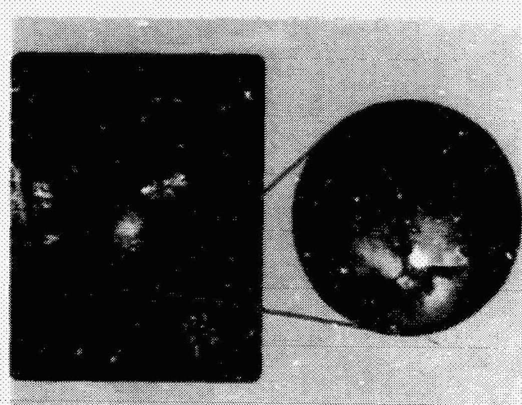
**Science Instruments ................ 25**
Wide Field/Planetary Camera
Faint Object Spectrograph
The High Resolution Spectrograph
High Speed Photometer
Faint Object Camera
Fine Guidance Sensors



**Putting It Up, Making It Work ...... 35**
On-Orbit Maintenance Provided
Spare Parts Available

**The Space Telescope Science Institute** .......................... **42**
TDRSS to Return Data
Schedule Adjusts to "Opportunities"

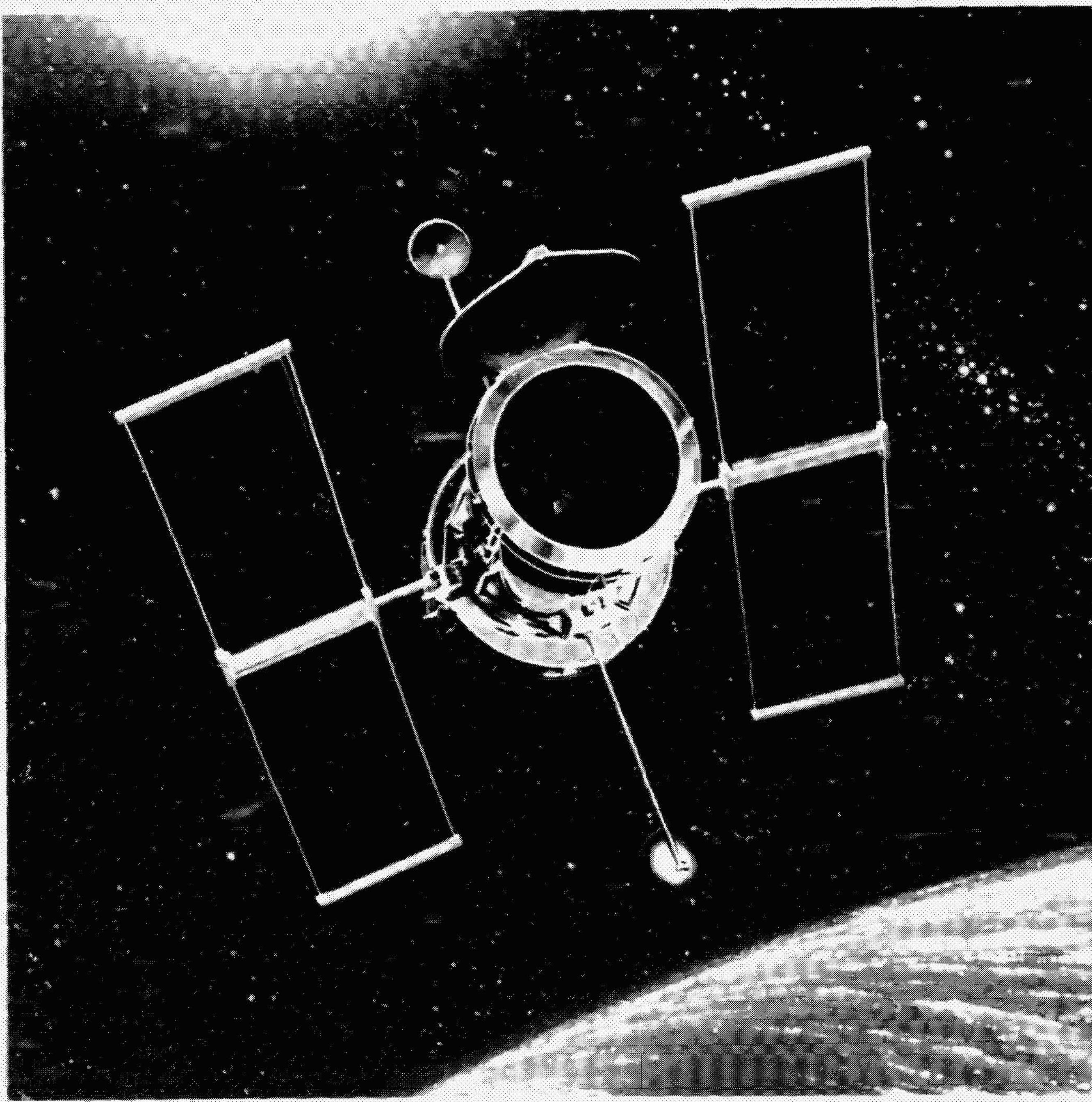
**Astronomy Enters the Space Age** .... **44**
Many Sciences and Technologies Involved



**Some Things Space Telescope Will See** .............................. **45**
Galaxies and Stars
Planets

**Space Telescope Responsibilities** .... **63**
Two Principal Contractors
NASA's Role
ESA's Role
Science Working Group
Credits and Acknowledgments
About the Author

*"The new telescope will be able to peer far out into space and far back in time."*



# Space Telescope

## *One of Space Shuttle's First Major Scientific Payloads*



The year 1985 is eagerly anticipated throughout the science world as the time scheduled by the National Aeronautics and Space Administration for orbiting Space Telescope. All of the agency's astronomy efforts during more than a quarter of a century are expected to improve technologically by a quantum jump with this new adventure in discovery.

*From earliest recorded history people have gazed up at the sky and marveled at what they saw. Stars, planets, comets and meteors were mysterious, even frightening to them. Some people looked harder than others, plotting and measuring positions and movements.*

*They began to detect regular, recurring patterns in the movements of celestial objects —and the science of astronomy was born. As the new science grew, it became mingled with religion and prognostication. The astronomers, who were just as much astrologers, became so proficient in their studies that they could predict the movements of planets years in advance.*

*But they weren't able to determine the precise nature of the lights they watched in the night sky. That would not come until the invention of an optical instrument called the telescope. In 1610, the Italian scientist Galileo Galilei turned his telescope toward the heavens and caught our first glimpse of what was really there. He saw craters on the Moon, a large spot on Jupiter plus four of its satellites, and projections coming from Saturn, later to be discerned as rings. It was the first step toward opening the universe to human examination.*

*More than 350 years later, a second major step into the universe occurred when spacecraft were launched from Earth. Rockets were attached to assemblies of scientific instruments, computers and radios, and boosted them out into the solar system. These astronomical and planetary vehicles ventured out beyond the filtering effects of Earth's atmosphere, saw clearly, and even directly sampled worlds other than our own. Thousands of new discoveries were made, expanding our horizons in a way that eclipsed even the wildest imaginings of early authors of space fiction. At last the universe was becoming real—less mysterious to Earthlings.*

And now the Space Telescope is about to exceed all of its optically-equipped predecessor spacecraft. Astronomers predict an unprecedented leap in our knowledge of the universe. The difference between Space Telescope and optical telescopes viewing the sky from present ground observatories can be compared to the difference between Galileo's first telescope and its predecessor, the human eye.

The new telescope will be able to peer far out in space and back into time, producing imagery of unprecedented clarity, of galaxies, star systems, and some of the universe's more intriguing objects: quasars, pulsars, and exploding galaxies. The Space Telescope will be able to do this because it will view the cosmos from its 600-kilometer (373-mile) altitude orbit via a 2.4 meter (94.5-inch)-diameter mirror. In contrast, the large five-meter (200 inch) telescope at Palomar Mountain, California, and all other ground

observatories, are handicapped by looking through the Earth's atmosphere.

Looking through our atmosphere into space, even with the most advanced telescopes available, presents an insurmountable problem—the atmosphere itself. In optical astronomy the best observing conditions occur only a relatively few nights a year. Observations on other nights are either blocked by bad weather or diminished in clarity by haze or heat currents. Besides visible light only a few very narrow bands of radiation, in the infrared and radio portions of the spectrum, can penetrate our atmosphere. Looking out through the atmospheric envelope that surrounds Earth is like looking up from the bottom of a pond or lake. The light is distorted, causing blurred images.

## *Distortion Eliminated*

The Space Telescope won't have this distortion problem and its imagery will be sent to Earth by electronic means, to be converted into clear pictures that astronomers and other scientists can study. The instrument will be able to see objects 50 times dimmer than anything seen now, and it will be able to observe for 40 percent of a 24-hour day on the average.

Observations from the Space Telescope will not be accomplished only in the visible spectrum. Onboard instrumentation will allow scientists to collect data from other forms of radiation over a wide spectral range. Spectrum analyzers or spectrographs in the observatory will split ultraviolet and visible light into their components and measure the intensity of the incoming radiation. Resulting spectral data will enable scientists to study the physical composition of objects in the universe and their chemical and atomic structures.

This new instrumentation will be used in observing our own Solar System as well as deep space. Space Telescope will be able to view our planetary system routinely, with a level of detail that can only be bettered by sophisticated spacecraft flying near or orbiting the planets. Astronomers will examine the clouds of Venus, the polar ice caps and deep valleys of Mars, and the dynamic atmosphere and moons of Jupiter. The rings, moons and clouds of Saturn will also be observed and the Space Telescope will even furnish us information about the outermost planets, Uranus, Neptune, and Pluto, that ground observations can not obtain.

Observations of the planets are helpful in understanding our weather, resources, and origins. These observations will be useful later in analyzing the feasibility of exploiting the resources of our entire planetary system.

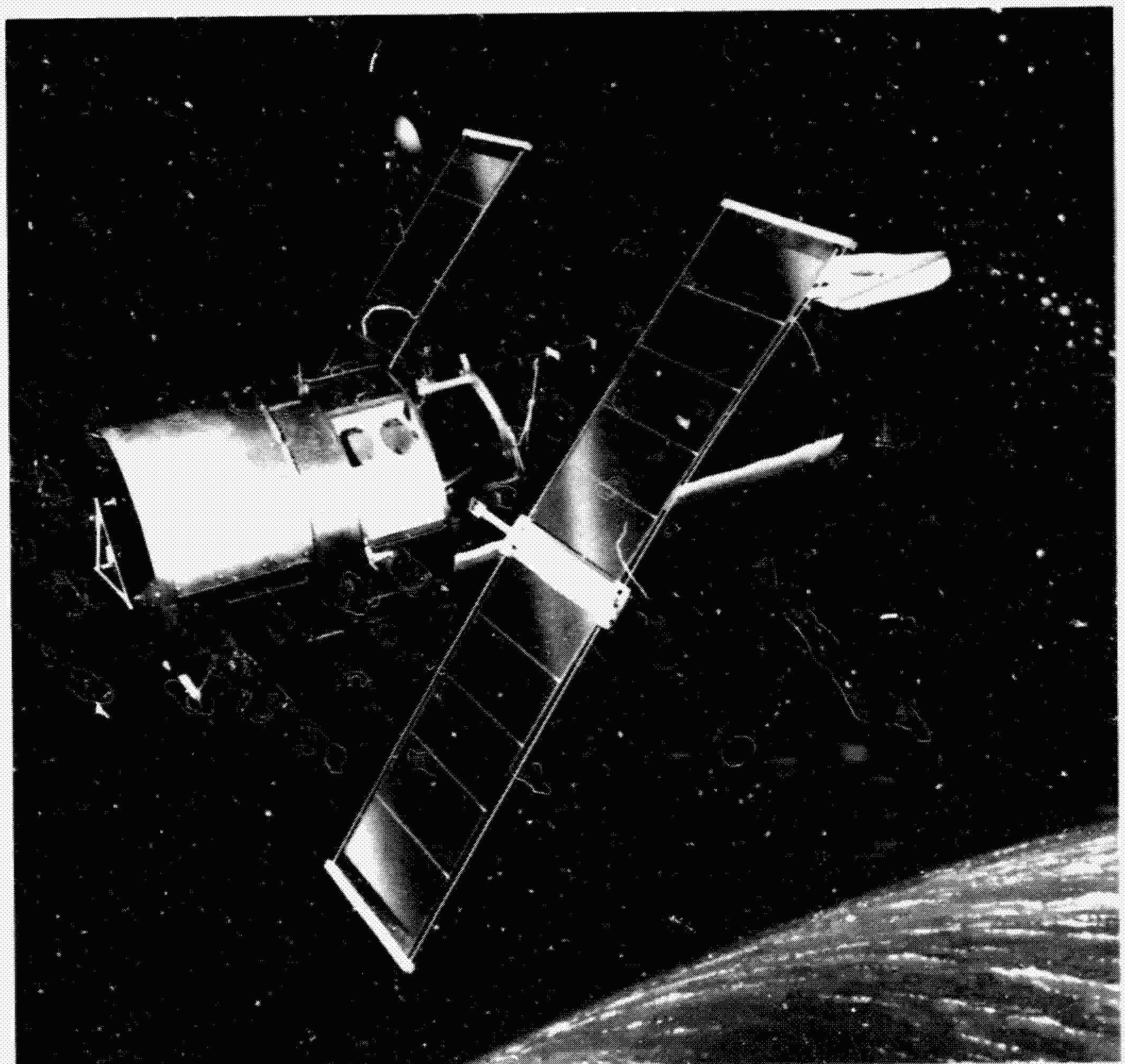
Not only will the Space Telescope provide information about our own Solar System, but it will also be used to search for clues of the existence of other solar systems. Although the telescope may not be able to see any planets that might be orbiting around even the next nearest star, Alpha Centauri, it should be able to note any perturbations in motions of nearby stars that would indicate the presence of orbiting planets.

There are 37 stars within 15 light years of our own Solar System and 10 Sun-like stars within 10 light years. The Space Telescope will be directed toward these stars and toward the 100 to 500 additional nearby stars that might host planetary systems.

Should the telescope detect planetary systems around any of these stars, it would raise new possibilities that extraterrestrial life, even intelligent life, may exist.

## *Study Star Development*

Beyond observing the planets and potential solar systems, astronomers are interested in viewing the many gas clouds in our





*Space telescope shown in orbit. Space Telescope will have no distortion problem and its images and spectral data will be sent to Earth by electronic means. It will be able to see objects 50 times dimmer than anything seen now.*

galaxy and in nearby galaxies. It is expected that stars in various stages of development will be studied. A composite history of the birth of stars, from condensation of gas to the ignition of their thermonuclear furnaces, may result. There is even the possibility that the birth process of solar systems might be observed.

Stars, like everything else in the universe, have life cycles. At the end of the cycle, a star may exhaust its thermonuclear fuel and quietly fade into darkness. A star may, on the other hand, put out one last burst of energy and destroy itself in a catclysmic explosion called a supernova.

Although supernovae are extremely rare phenomena, the Space Telescope will investigate this end of stellar life cycles by studying the gas cloud remnants of stars that have gone supernova in the past.

## *New Knowledge Changes Concepts and Theories*

Until the Age of Space began at the end of World War II and got its big boost in 1957 with the first Earth satellite, Russia's Sputnik, the universe was conceived as being rather quiet. Some scientists considered it a serene place composed of stars and galaxies.

Within the past decade, most astronomers have rejected the earlier concept of a quiet universe. They now see the cosmos as harboring high-energy objects, million-degree gases, and particles moving close to the speed of light. Our universe is violent and filled with cataclysmic events.

We are now aware of quasars, the most powerful and distant objects ever detected. But what causes the enormous release of energy by a quasar that indicates it emits more energy than the most powerful known galaxies in the universe? What propels the radiation across millions, even billions of light years to Earth? Space Telescope may give us some answers.

## *Seek Origin of the Universe*

Even more perplexing than the mysteries of the quasars are questions about the origin and nature of the universe as a whole. Many astronomers believe that the universe started from one timeless point—a darkness transformed through an explosion, commonly described as the "Big Bang"—into an expanding sphere of energy and matter that spewed out to occupy the emptiness of space.

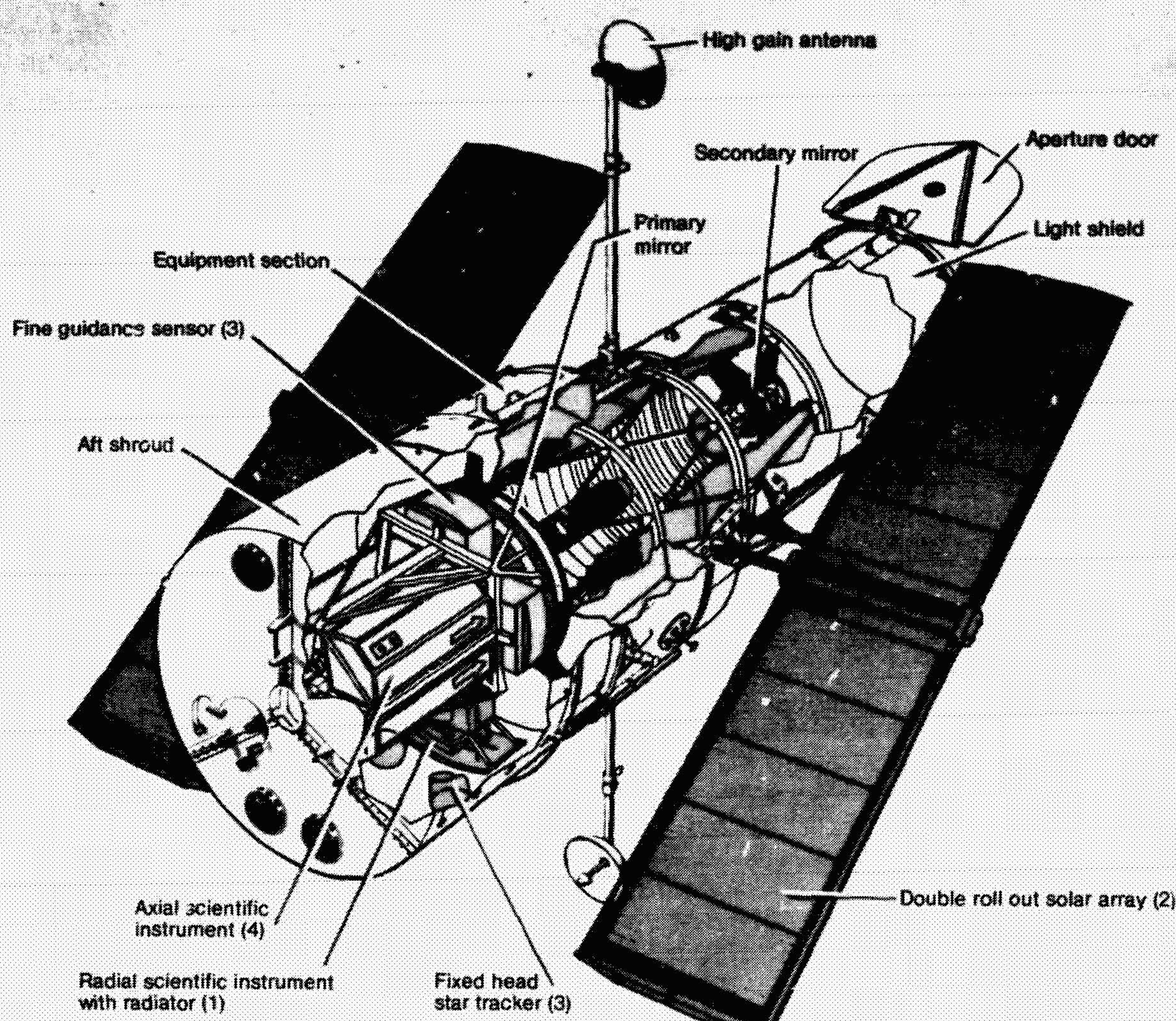
At some point this massive, tenuous sphere began cooling down. It coalesced and became the matter we now call galaxies, stars, and planets—the universe. Why did this happen? How did it occur? This mystery may be solved by Space Telescope.

Although the universe is believed by most astronomers to have started this way, it is not known if it will continue to expand into oblivion or will finally stop and fall back on itself due to gravitational collapse.

This would entail a grand sweep of all stars and galaxies into one awesome singularity or mass that may ultimately explode again, forming a new universe. This is called the Oscillating Universe Theory.

Currently, the weight of evidence is against oscillation because enough matter has not been found to cause the gravitational collapse, to reverse the present expansion. Some galaxies near the edge of the cosmos are believed to be traveling at speeds approaching that of light—297,600 km (186,000 mi.) per second. Although some believe there may be enough matter between the galaxies and the stars or possibly in immense black holes in space that could stop the expansion, there is only indirect evidence that this is true.

Another theory, the Steady State Theory, postulates that the universe constantly re-




*Space Telescope comprises three major systems: The Support Systems Module, five modular scientific instruments, and the Optical Telescope Assembly. This artist's illustration shows the Support Systems Module and the Optical Telescope Assembly with the scientific instruments in place.*

news itself by creating new matter between the stars and galaxies, a process resulting in an essentially unchanged universe. This idea counts fewer adherents in today's astronomy community.

The question of an open- versus -closed universe might be solved quickly by the orbiting observatory because of its capability for making precise distance measurements of objects in deep space. Such measurements are needed to arrive at an accurate cosmological distance scale.

With the telescope's powerful instrumentation, scientists will be able to compare the rate of recession of nearby galaxies with that of distant galaxies.

## A Look Into the Past

Distant galaxies are galaxies as they were in the past, their light having journeyed through millions, even billions of light years of space. (A light year is the distance traveled at the speed of light in an Earth year.) This means we will soon be able to compare the speed of expansion of the universe of the distant past with present expansion rates. If scientists confirm that expansion of the universe is slowing down, the mutual gravitational attraction of all atoms in the cosmos is presently considered the only phenomenon that could cause the deceleration. Some 100 times more than the known matter would have to exist in the universe to cause a slowing of the speed of expansion.

Where is all the matter necessary to slow it down, to collapse the billions of galaxies in the universe into one enormous mass? Is it in the gas clouds between the galaxies? Are there unimaginably huge black holes which have already sucked up galaxies into enormous gravitational singularities from which not even light can escape? The Space Telescope may provide some of the answers.

Although many astronomers hope to settle fundamental questions such as the open-versus-closed universe, it is also agreed that probably the most revolutionary discoveries from using the Space Telescope may be those we have not yet even imagined. Vast areas of space that cannot even be visualized now, because there is no way to see them, will become part of cosmological textbooks of the future. Possibly the greatest discoveries will come many years, even decades after the Space Telescope has been placed in orbit. This revolutionary space observatory will be maintained, supplied with new instrumentation as technology advances and possibly even taken back to Earth by the Space Shuttle for complete refurbishment. It will be used by the world scientific community until at least the end of the century.

## Back to the Beginning

This new observational tool may open wide a door that is now barely ajar. When it is fully opened we may see, among other wonders, the universe as it was much earlier in its history.

We may even see the universe as it appeared just after its formation, an estimated 15 billion years ago. No instrument on Earth, including the huge telescope at Palomar Mountain, the largest in the United States, can approach the space observatory's capability.

This sophisticated instrument, from its orbiting perch above Earth, will see objects 50 times fainter and seven times farther away than any ground observatory. In addition, it will be able to observe a volume of space equal to 350 times more than we now see from Earth. Today we know of at least 100 to 200 billion stars in our Milky Way galaxy and astronomers believe there are at least 100 billion galaxies of greatly differing sizes in the universe. But what will we be able to see with the new spacecraft?

What the human eye will view via this new spacecraft for the first time will be literally a part of the universe 350 times larger than has ever been seen before, composed of countless galaxies invisible to us before Space Telescope. Primeval galaxies may be seen as they were formed, as they appeared shortly after the beginning of time. Some astronomers theorize that the Space Telescope may be capable of virtually "looking back" and perhaps viewing much of the universe as it may have been just after the Big Bang.

# Space Telescope Background

Ideas for the Space Telescope have been considered for some time. More than 50 years ago German rocket expert Herman Oberth suggested that a way to vastly improve astronomy would be to get a telescope above the Earth's atmosphere to eliminate the difficulty all earthbound observatories experience. They cannot penetrate Earth's air blanket with the desired clarity from below, and most electromagnetic radiation, including ultraviolet and infrared, can not penetrate the atmosphere from above. A great solution, but nobody took it very seriously at that time.

In 1962, NASA asked the Space Science Board of the National Academy of Sciences to put together two study groups. The space agency wanted recommendations for future astronomy payloads. Two sessions were held, one at the State University of Iowa and the other later, at Woods Hole, Massachusetts. Ideas were discussed, with the participants aware that NASA already had a sophisticated astronomy observatory, Orbiting Astronomical Observatory (OAO), under study. This spacecraft was considered the agency's first major step in the astronomy field.

The first operational OAO was to carry a 75 cm (30 in.) telescope capable of returning data in the ultraviolet, but it was not in the same league with what the State University of Iowa study group recommended: "a much larger instrument, say 100 inches or more, would represent a truly enormous investment for astronomy. For this reason, it is vital that its scientific justification receive the most careful and comprehensive consideration by the astronomical and related scientific communities."

This viewpoint was not unanimous. A minority report pointed out that the upcoming OAO would satisfy the initial requirements of the astronomy community. They felt it "premature" to appoint another study group, as the majority recommended, to study a larger space telescope.

Engineering studies led to a 1965 Science Board recommendation to NASA favoring a large Space Telescope.

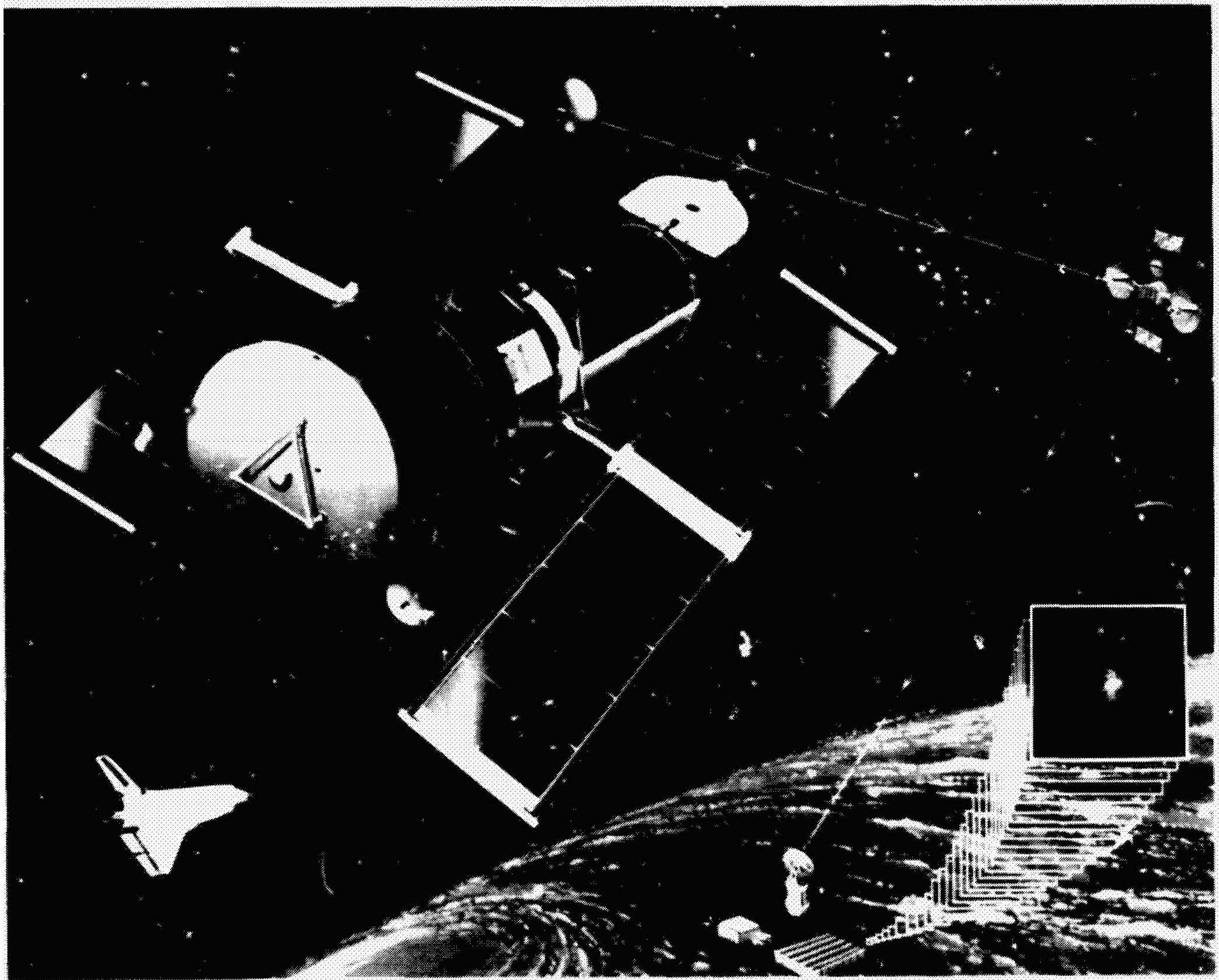
## Scientists Support Telescope Concepts

By the early 70s, there was strong support from the scientific community as a whole, as well as from industry. Many leading technical and scientific people had gone into great detail to examine all aspects of the project and there was agreement to go to Congress for the necessary funding to make it a reality.

Congress was told it was the next logical step in astronomy and had the astronomy community's recommendation. With the advent of an operational Space Shuttle in the 80s providing the ability to establish, operate and maintain in orbit a major space observatory, a large telescope in space became feasible.

Congress gave its approval in 1977 and Space Telescope became an official NASA program.

*Space Telescope in orbit and receiving stellar light which goes into the spacecraft's aperture, strikes the primary mirror, is reflected back to the secondary mirror where it is again reflected through the hole in the primary mirror to the focal plane. Here the scientific instruments pick up the image which is transmitted by the Tracking and Data Relay Satellite which transmits the data to White Sands, New Mexico, which in turn transmits it to Goddard Space Flight Center, Greenbelt, Maryland. Goddard Center then corrects the raw data and sends it to the Space Telescope Science Institute. (Artist's concept)*



# The Spacecraft

The Space Telescope will be built to work much like a ground observatory. The principal concept will be to collect more light than can be gathered by the human eye, concentrate it on a focal plane and record the image formed there. In principle, it is no different than the reflecting telescopes invented by Guillaume Cassegrain and James Gregory in the 17th Century.

Its launch weight will be about 11,000 kilograms (25,500 lbs.); it will be 13.1 m (43.5 ft.) long and have a diameter of 4.27 m (14 ft.). Two large solar panels that will be unfurled in space are attached to the exterior of the spacecraft and will measure 2.3 by 11.8 m (7.8 by 39.4 ft.) in orbit. The power supply system, consisting of the solar arrays, batteries, and power conditioning equipment, will supply a minimum of 2,400 watts to the spacecraft components beyond two years from the beginning of the mission. This will be sufficient to recharge the spacecraft's six nickle-cadmium batteries after it completes the nightside portion of its 90-minute orbit. Before deployment, the solar arrays will be enclosed in a 38 cm (15 in.) diameter cylinder pivoted against the side of the telescope.

Data are transmitted and received on Earth by Tracking and Data Relay Satellites in synchronous orbit 35,680 km (22,300 miles) over the Atlantic and Pacific Oceans. These powerful new tracking satellites ultimately will replace most of the space agency's worldwide ground tracking station network and will also support Space Shuttle operations.

## Imagery Radioed to Earth

The Space Telescope consists of an Optical Telescope Assembly, a Support Systems Module, and Scientific Instruments. They all work together as one unit in space to return imagery and other information to Earth.

The heart of the spacecraft is the Optical Telescope Assembly where the reflecting Cassegrain telescope is located. This type of telescope features a system where light from a star or other object travels through the aperture, down the assembly past the smaller secondary mirror, and strikes the large (2.4 m; 94.5 in.) primary mirror. The light is then reflected 4.6 m (16 ft.) back to the 0.3 m (12.2 in.) secondary mirror where it is narrowed and intensified into a small diameter beam. The beam travels through the 60 cm (24 in.) hole in the primary mirror to the focal plane just behind it. The focal plane is 1.5 m (4.9 ft.) behind the front surface of the primary mirror.

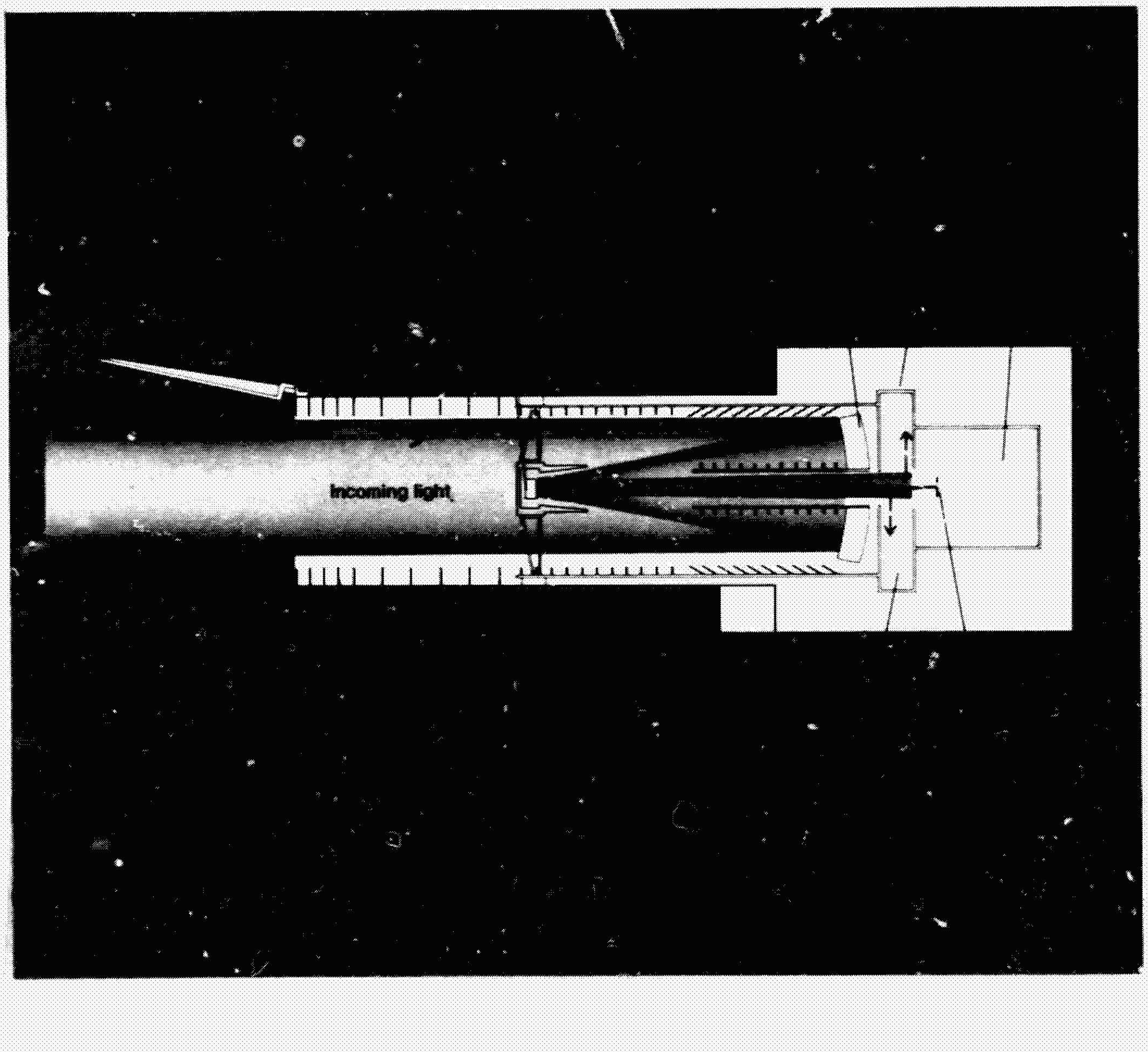
At the focal plane the light originally captured by the big mirror is converted into a focused image. Parts of the image enter the apertures of the scientific instruments and are transmitted as data to Earth. The mirrors will be kept at a nearly constant temperature so that images at the focal plane will have no distortion in their resolution due to environmentally-induced surface changes.

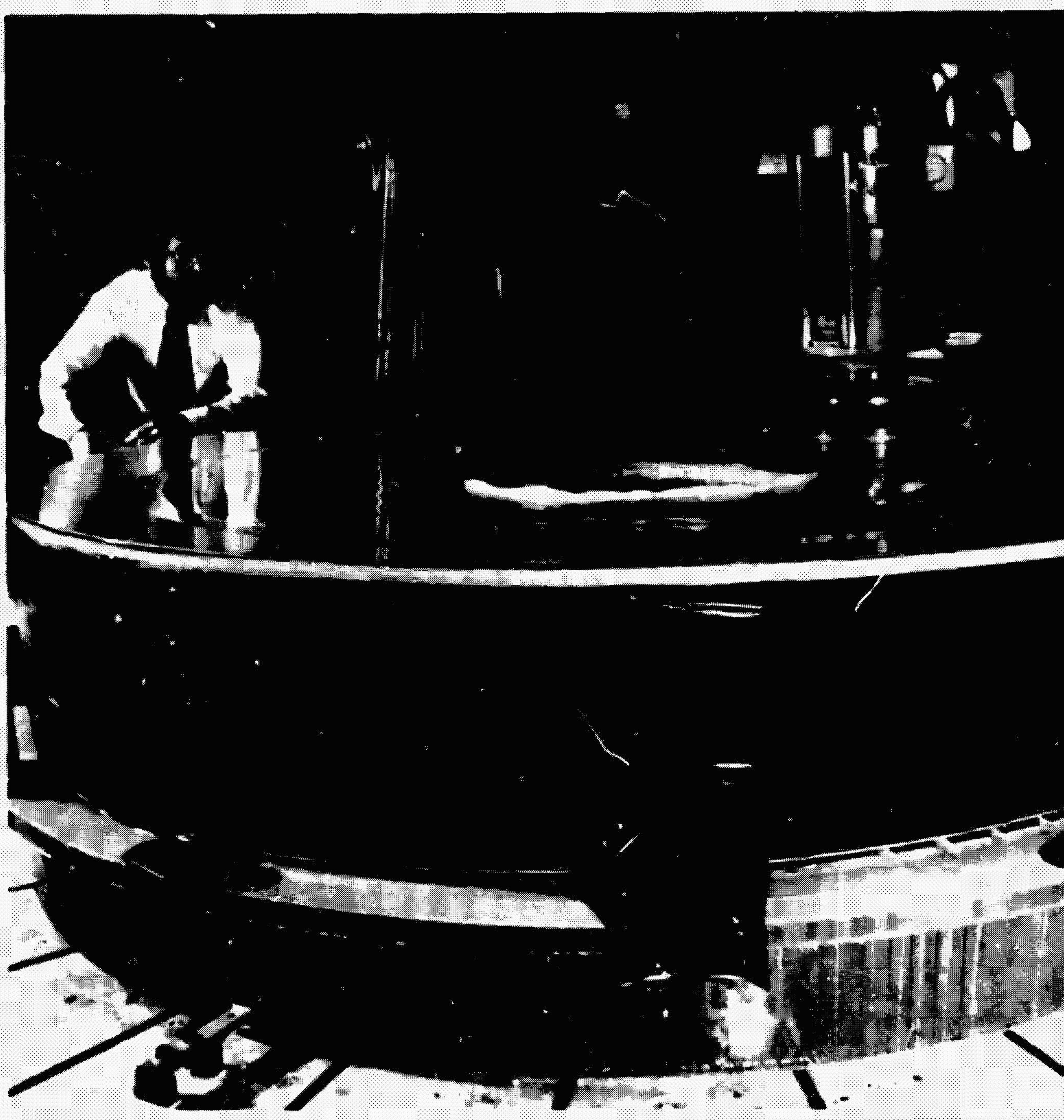
Pictures and other scientific data are converted to electronic signals and are

transmitted via high-gain antennas at a rate up to 1 megabit (one million bits) per second. After being received on Earth, the data can be reconstructed into images and spectrograms.

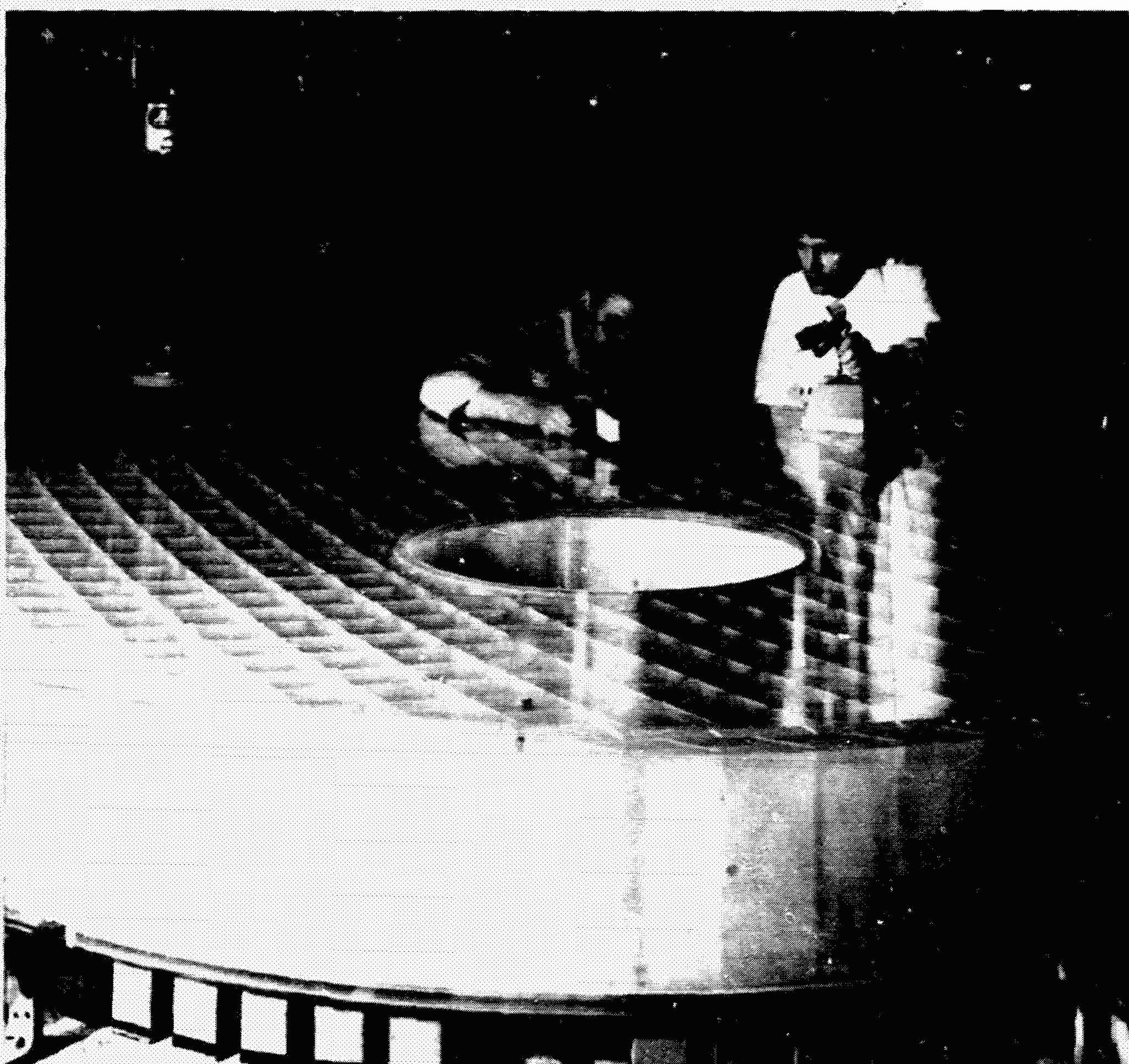
The primary mirror is made of ultra-low expansion titanium silicate glass, with an aluminum-magnesium fluoride coating. To reduce weight, the front and back plates are fused to a honeycomb core.

*This sketch shows the path of light entering the Space Telescope. A series of light baffles protect sensitive optical components.*

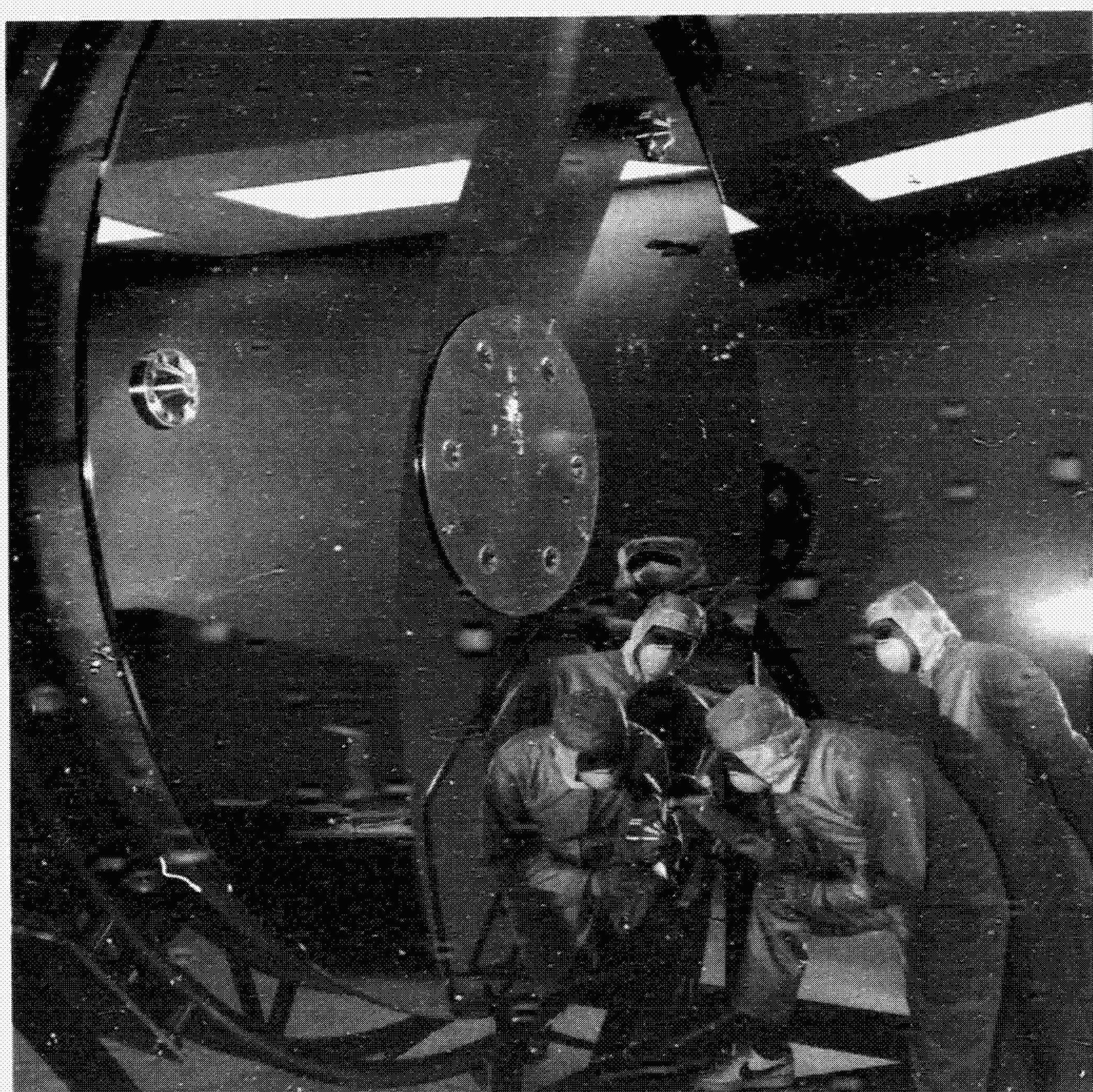




Grinding the primary mirror at the Perkin-Elmer Corporation



*The primary mirror of the Optical Telescope Assembly for the Space Telescope is 2.4 meters (8 feet) in diameter and weighs 829 kilograms (1,827 pounds). The mirror is made of a lightweight silica glass core fused between faceplates of silica glass.*



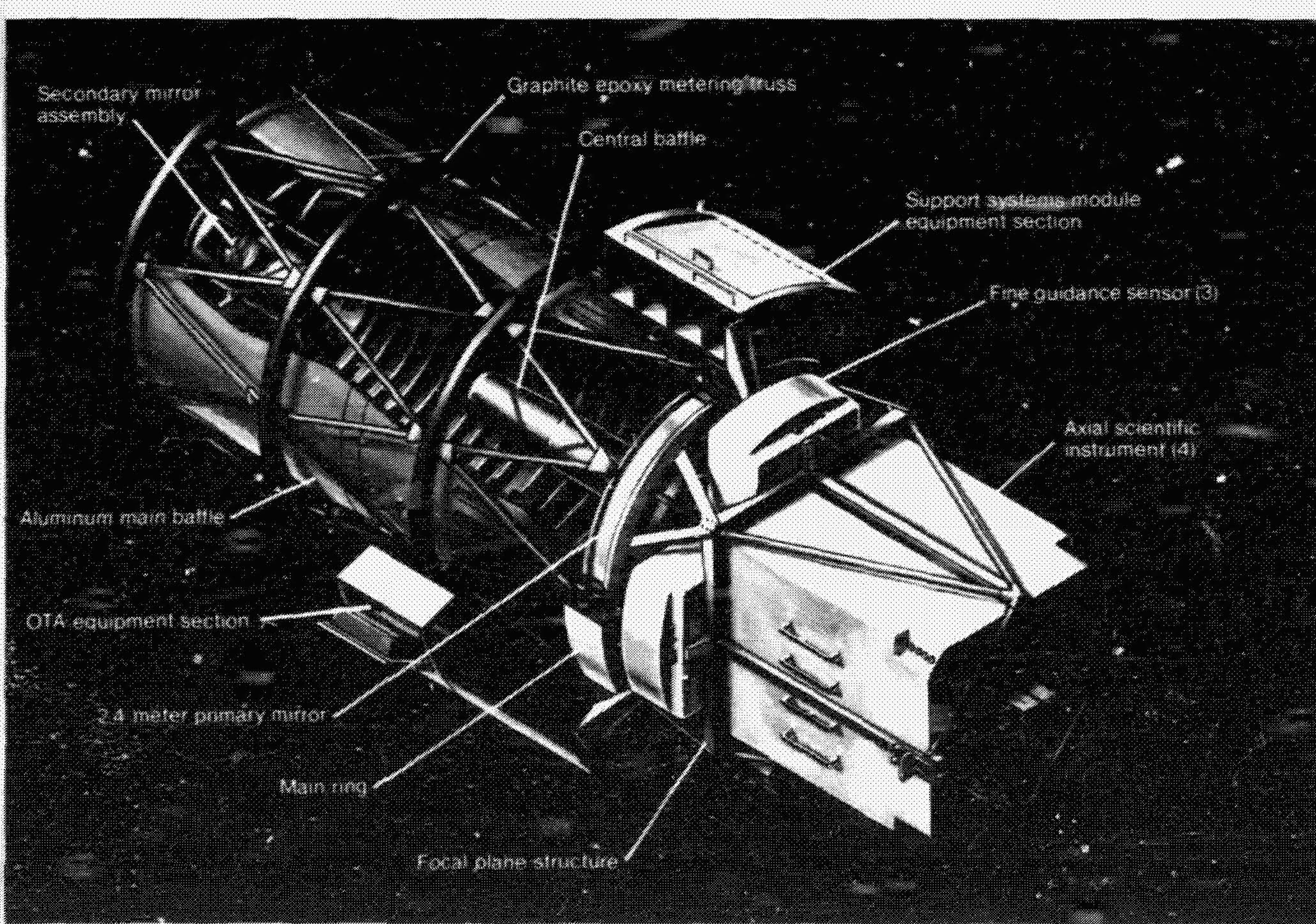
*Space Telescope's primary mirror's reflective aluminum and magnesium fluoride coating has been applied.*

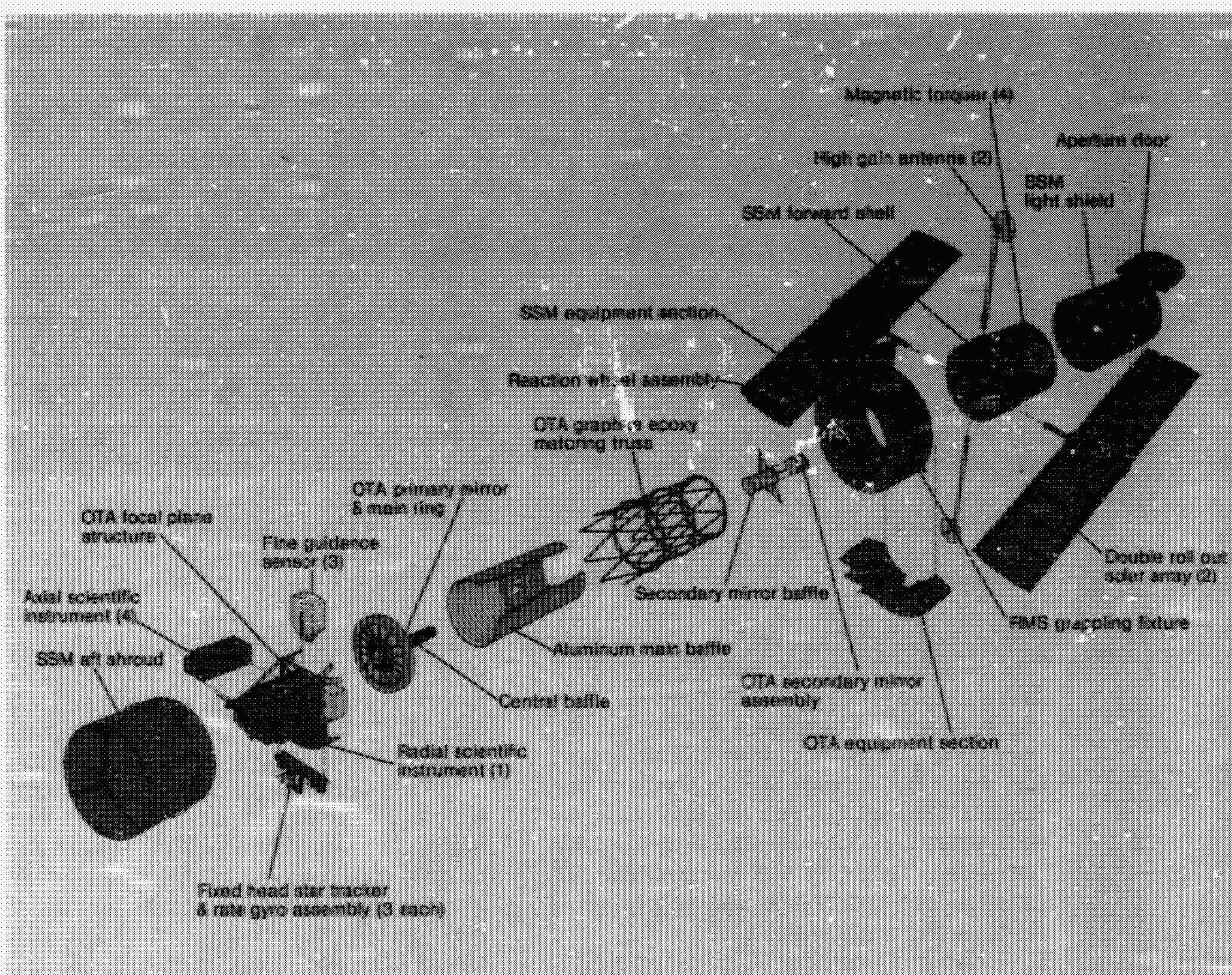
## *Modules Are Replaceable*

The Optical Telescope Assembly (OTA) and the Scientific Instruments sections are adjoining. The focal plane structure (FPS) is joined with the main ring. The scientific instruments are fastened to the focal plane structure by latches to permit removal on orbit. The five scientific instruments and three fine guidance sensors are located just behind the primary mirror at the focal plane. The instruments are housed in modular units so that each module can be removed by astronauts and replaced by another unit or, in the future, by units of more advanced design. Shuttle crew members can do this by pulling a unit out, as each module is independent of the other.

The Support Systems Module (SSM) provides the Telescope Assembly and the Scientific Instruments with the power, communications, pointing and control, and other support systems required for successful operation.

*This artist's concept shows how the Optical Telescope Assembly and the Scientific Instruments sections are joined (with the instruments, designed as modular units, located just behind the telescope's primary mirror).*






*The Space Telescope's support systems are shown in this illustration, indicating how they are assembled in a modular design within the telescope's outer shell.*

The Module's shroud encloses the entire telescope and instrumentation assemblies. Attached to the shroud are the solar paddles and the high gain antennas. Small, low gain antennas are attached to the front and rear of the shroud, and are omnidirectional. The Support Systems Module is divided into four main sections: the light shield, the forward shell, the equipment section, and the aft shroud. These four pieces fit together like stacked cannisters, to enclose the telescope assembly and scientific instruments.

The aperture door, which also serves as a light shield, is located on the forward portion of the Support Systems Module. The telescope must be shielded against the

Sun, Earth and Moon so scientific instruments are not damaged by a flood of light. While in operation it will not be turned to within 50 degrees of the Sun. This precludes observations of the planet Mercury. Internal baffles in the Support Systems Module door prevent scattered light from degrading the focal plane image. The central baffle is located just in front of the the primary mirror, while a secondary baffle fits just behind the secondary mirror. A large aluminum main baffle extends from the primary mirror to just beyond the secondary mirror.

Just behind the light shield and the forward shell is the equipment section of the spacecraft. This doughnut-shaped section is made up of 10 compartments that house the electronic and control modules. Access to many of these modules will be relatively easy as some compartments can be opened from the outside, via a hatch or access door. An astronaut opens the cover to get at the module needing replacement, disconnects the module from the plug-in compartment and inserts a replacement. Among the components in the equipment section are the rate gyros and the batteries. The aft shroud fits over the section which contains the science instruments and the fine guidance sensors. Access covers on this shroud enable astronauts to get at the instruments and sensors, for removal or maintenance, just as in the equipment section.

Handrails and portable foot restraints are fixed on the external surface to permit astronauts to perform their maintenance and refurbishment tasks. Four magnetic torquers are also located on the shroud exterior, working with four reaction wheels within the Support Systems Module equipment section, to control the spacecraft's attitude in space. The magnetic torquers are magnetized metal rods controlled by an onboard, triple-redundant computer to align the spacecraft with the Earth's magnetic field. The reaction wheels also receive torque commands from the computer, to point the telescope within an accuracy of 0.01 arc seconds or less.

## *Precise Pointing Planned*

The pointing control system uses six rate gyros and two fine guidance optical sensors to provide roll, pitch and yaw information and is designed to keep the observatory locked on a subject for extended periods, accurately to within 0.007 arc seconds. This is the equivalent of locking onto an object the diameter of a dime located in Boston from Washington, D.C., or, if the telescope could extend a beam 1000 km (600 mi.) long, its stability would be such that the far end of the beam wouldn't move any more than three cm (1.2 in.) off center. The telescope can be turned and changed from one object to another if observers wish to acquire another subject. This motion can occur at a rate of 90 degrees in 20 minutes. Astronomers anticipate that observations of very faint objects may take as long as 10 hours or more of continuous exposure.

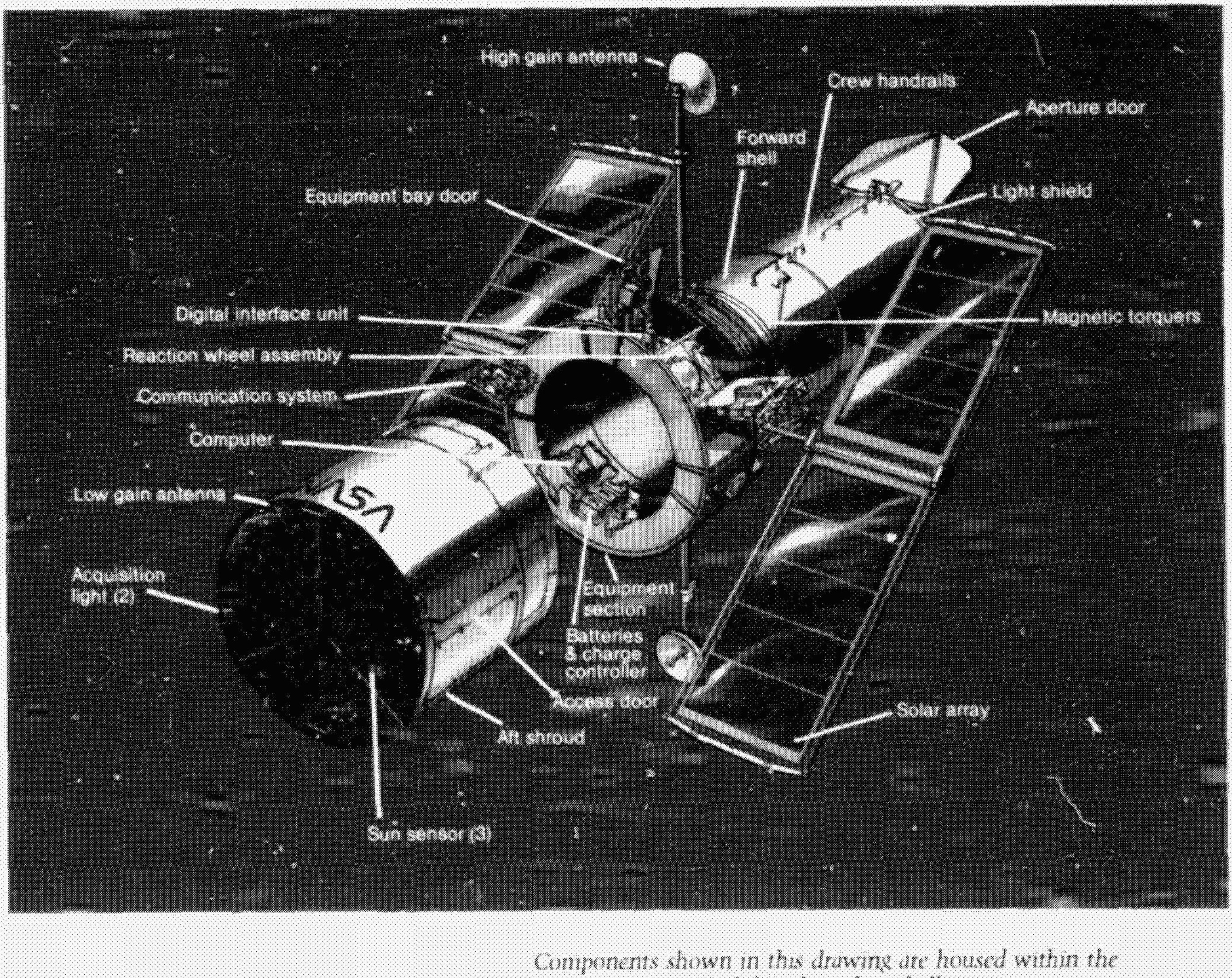
Temperatures inside the observatory are controlled actively and passively. This means thermal coatings on the spacecraft's exterior and interior insulation, and thermostatically-controlled electric heaters, to make certain proper temperatures are maintained. One side of the spacecraft, the cold side, seldom sees the Sun. Subsystems that require the coolest operating temperatures, the batteries for example, are located on the cold side.

The Data Management Subsystem and its central computer are the nervous system and brain of the observatory. The triply-redundant computer processes and controls all information required for the operation of the spacecraft. Most commands are routed through, or stored in and executed by, the computer.

The Scientific Instrument Control and Data Handling Subsystem has its own computer which accepts, decodes and distributes commands for the scientific instruments. It also serves as the focal point for putting scientific data in the right format to be recorded or transmitted directly to Earth.

The Instrumentation and Communications Subsystem acquires onboard engineering data, transmits it to the ground and receives commands from the ground which are then processed and executed by the Data Management Subsystem.

The electrical Power Subsystem provides power generation via the solar arrays, energy storage by the onboard batteries, and manages the control and distribution of energy to the spacecraft. An average of 2.4 kw is used for operation of all subsystems and instruments.




*Components shown in this drawing are housed within the Support System Module's shroud or shell.*

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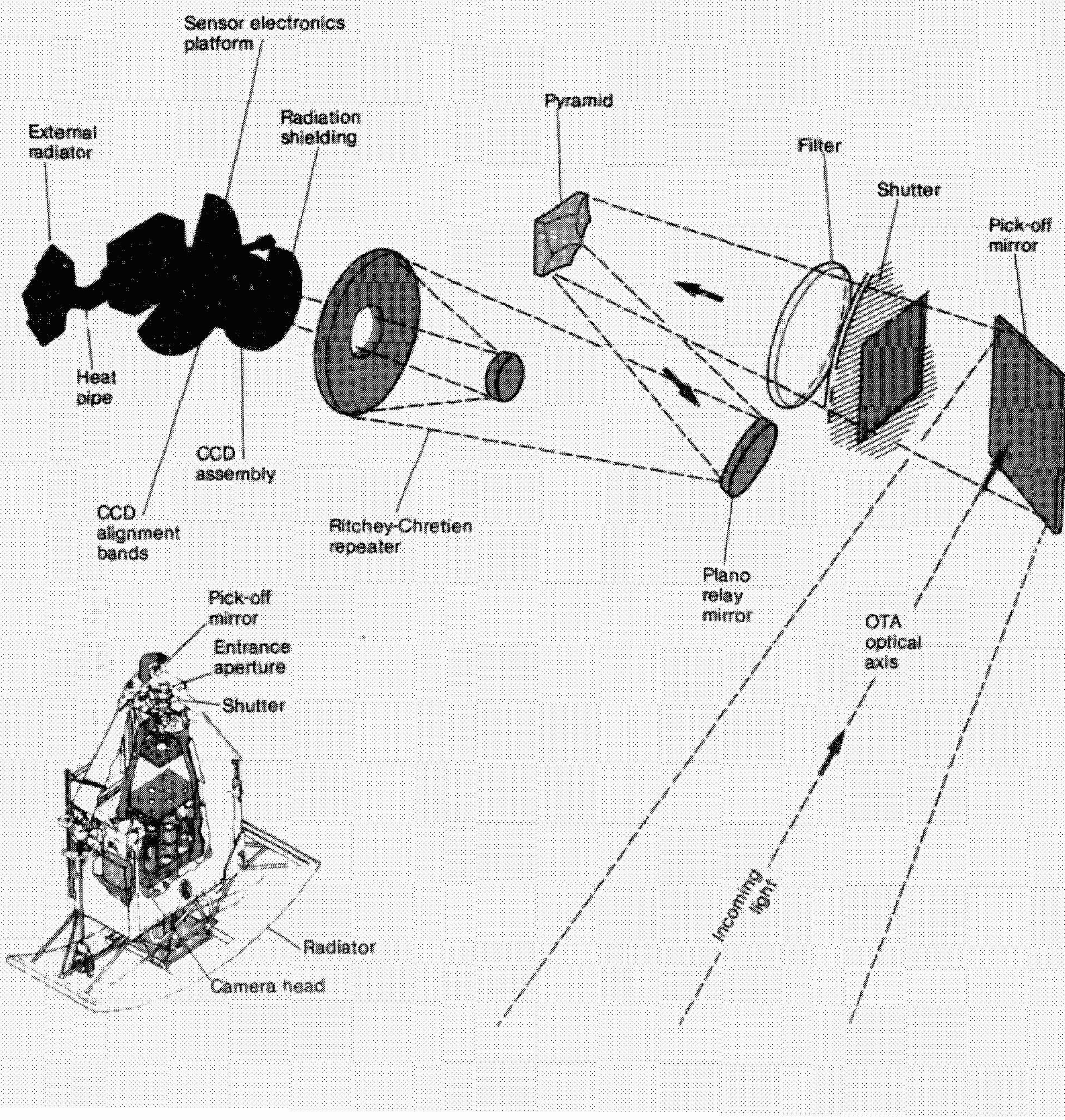
*Wide Field/Planetary Camera optical design concept, showing only one channel of its two optical modes. This camera is designed to provide excellent spatial resolution over both small and large fields of view (up to 2.7 by 2.7 arc minutes).*



# Science Instruments

The five scientific instruments, four U.S. and one European, are located behind the primary mirror, at the focal plane, where they can pick up the light from the telescope. These are the Wide Field/Planetary Camera, Faint Object Spectrograph, High Resolution Spectrograph, High Speed Photometer, and the Faint Object Camera, the latter provided by the European Space Agency. In addition, the Fine Guidance Sensors, because of their ability to accurately locate stars, are considered a sixth scientific instrument.

Each instrument is housed in a separate module. Four are in bays that run parallel to the spacecraft's axis. The wide Field/Planetary Camera, and three Fine Guidance Sensors are located in a section in front of the axial bay, but at right angles to the other modules. These instruments will draw 110 to 150 watts of power each. All are exchangeable during maintenance visits on orbit.

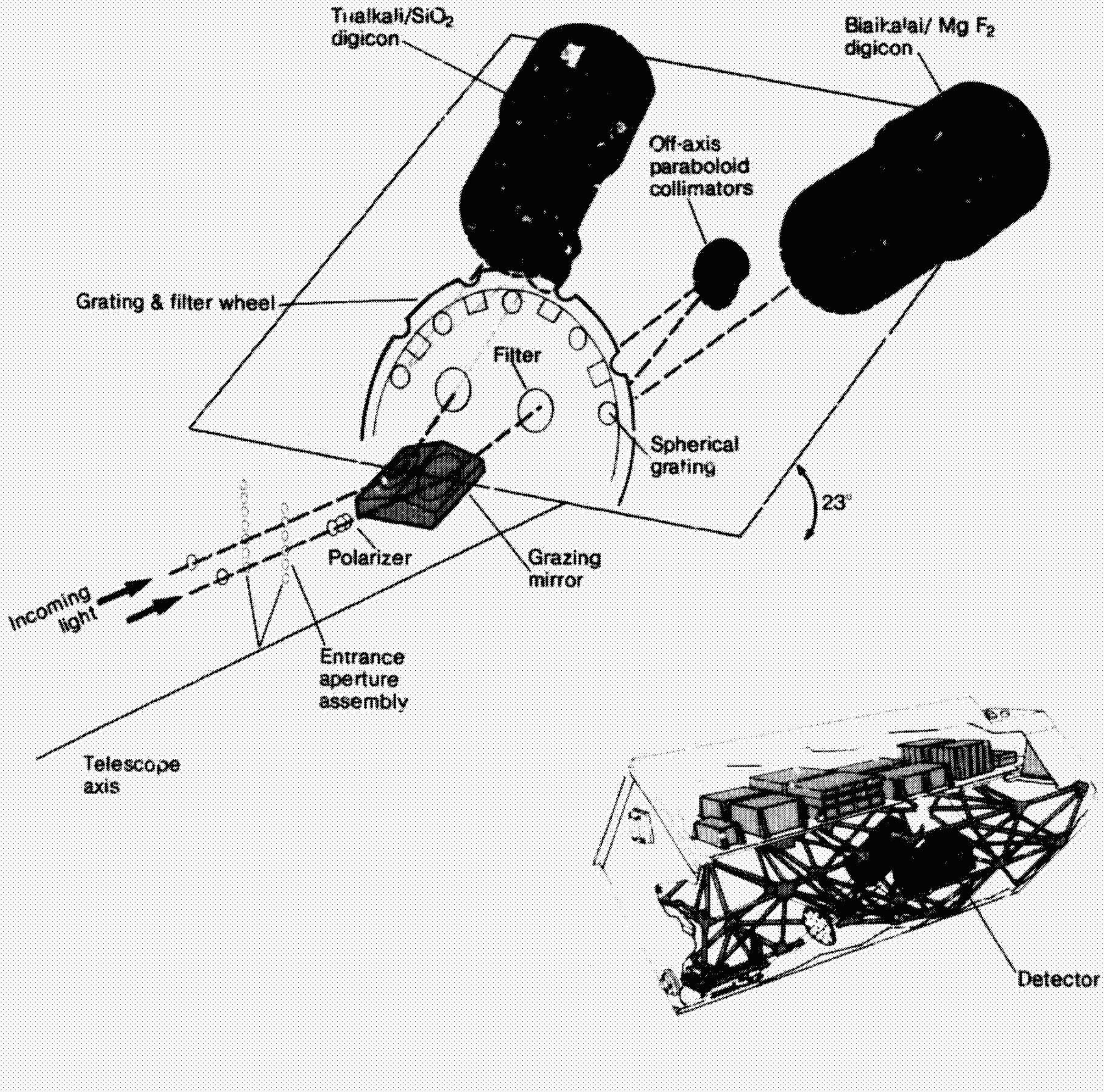
## *Wide Field/Planetary Camera*

This instrument can operate in two modes. It has a wide field capability at a focal ratio of f/12.9 that will permit examination of large areas of space, leading to accurate plotting of the spatial relationships of distant objects such as galaxies and quasars. High resolution images with the planetary camera's focal plane ratio of f/30 will also be possible in studying the planets in our Solar System (except Mercury). Images telemetered to Earth by radio will be far better than pictures produced through ground-based optical systems. Pictures of Jupiter, for example, will be comparable to images of the planet taken by the two Voyager spacecraft in 1979 and they will be possible on a regular basis, from Earth orbit. Resolution of the planets beyond Saturn is not expected to be as high when compared with eventual flyby pictures. The fine resolution of this instrument, expected to be better than ground-based resolution by a factor of at least ten, will sharpen our views of blurred, distant galaxy-like objects.

The camera is designed with a complex grouping of instrumentation and mirrors, so that the field of view is split by a pyramidal mirror into four separate portions which are focused onto four charged-coupled devices. These devices have been designed for receiving low light intensities at very high resolution. A portion of the image is received on each target plate and is subdivided into 640,000 picture elements (pixels). Light intensities of each pixel are transmitted to Earth via telemetry signals for assembly into images for study. Assembling information from different spectral bands is possible by directing the incoming light through any one of up to 50 spectral filters within the instrument.

Anticipated new science data which observers expect to obtain from observations made with the Wide Field/Planetary Camera will relate to:

- Cosmic distance scales
- Cosmic evolution
- The comparison of near and far galaxies




*Faint-Object Spectrograph optical design concept, showing the two independent optical channels which will provide the spectra of astronomical objects of the faintest possible magnitudes in the ultraviolet and visible wavebands.*

— Stellar population studies
— The distribution of energy in stars and compact objects
— Observations of stars in formation and supernovae
— Planetary atmosphere observations and comparisons
— Search for planets around nearby stars
— Cometary observations, including Halley's Comet.

## *Faint Object Spectrograph*

The faint Object Spectrograph is a versatile instrument that can obtain the spectra of extremely faint astronomical objects in the ultraviolet and visible wavebands. Light spectra of astronomical objects will be analyzed to study their relative distribution, from the ultraviolet through the visible. Light radiated from objects is a mixture of all colors of the spectrum and these colors indicate a broad range of energy as well as the presence of chemical elements that either emit or absorb light in a known way. Each chemical element will emit or absorb light under conditions related to temperature and the amount of that chemical element present.

Study of a spectrum tells us the nature of the source we are viewing. We will know whether it is hot or cold, dense or rarified, and even its chemical composition. Analysis of the spectrum also yields the distance away and velocity of the object being studied.

The faint Object Spectrograph is designed to pick up the image of a star, galaxy, inter-stellar dust cloud or other object that appears on the telescope's focal plane as a point of light. Then, via a system of optical mirrors and gratings that work like prisms, the light beam is spread out, from the ultraviolet through the visible.

The fanned-out beam is recorded on an imaging device called a Digicon Detector, which counts or registers the photons of light corresponding to the different positions of the incoming light beam. In effect, this is a picture of a finely-divided range of light which shows its intensity and distribution over the various wavelengths of the spectrum. The spectrogram is then transmitted to Earth for study.

The Faint Object Spectrograph will be used to:

— Observe the nuclei of active galaxies
— Define the amount and kinds of chemicals in galaxies
— Provide information on the physical properties of quasars
— Study the mysterious jets that appear optically in photos of quasars
— Study quasars believed to be at the nuclei of some galaxies
— Study comets before they are chemically changed by the Sun.

## *The High Resolution Spectrograph*

The High Resolution Spectrograph will be able to use the full resolving capability of the telescope to see much dimmer objects than previous spaceborne instruments. Although it performs in much the same way as the Faint Object Spectrograph it will be much more accurate because it will be using more light and resolving it into much finer increments. It will be looking at only the ultraviolet region of the spectrum, and seeing light that cannot reach Earth. This region or wavelength provides what astronomers believe will be the most detailed chemical composition information yet obtained on objects in space.

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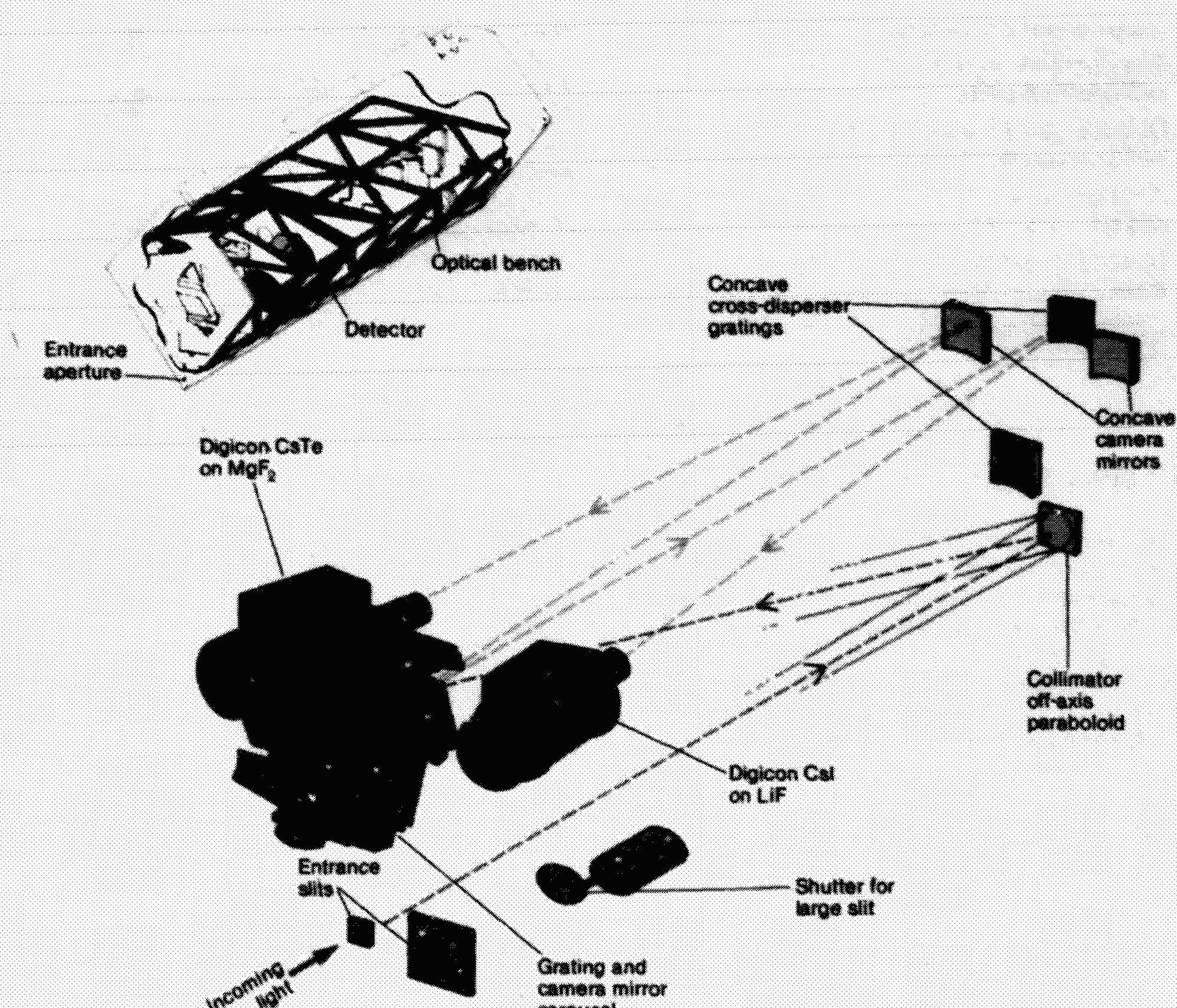



*Optical design concept for the High Resolution Spectrograph showing components which will obtain higher spectral resolution in the ultraviolet than has heretofore been possible in space astronomy*

Previous generations of spacecraft that could see in the ultraviolet, such as Copernicus Orbiting Astronomical Observatory, and the International Ultraviolet Explorer, have returned extremely interesting and important scientific information. However, the High Resolution Spectrograph will be able to detect objects 1,000 times dimmer than those observed by these earlier spacecraft at comparable or even higher spectral resolution.

This extremely fine resolution means that individual stars in crowded fields will easily stand out in the imagery of the High Resolution Spectrograph. In addition, binary stars that cannot be differentiated optically will be resolved so that each star can be studied separately.

The High Resolution Spectrograph will be able to study such objects as supernovae, active galaxies, bright quasars, and even phenomena in our own solar system. In the latter case, the telescope will look at planetary atmospheres, auroral activity, and search for deuterium in comets. Only a certain amount of deuterium, a chemical element believed to have been manufactured primarily in the Big Bang, is thought to occur throughout the universe. If it should be found in cometary gases, such a discovery could reveal more about the relation of our solar system to the original cataclysmic explosion.

The High Resolution Spectrograph will be used to:

— Investigate the physical makeup of exploding galaxies, quasars and other dense objects

— Study the loss of mass of one star to another in binary systems

— Measure the total amount of matter expelled in stellar explosions

— Investigate the physical makeup of the gas clouds

— Study the various stages of stellar evolution

— Define the atmospheric structure of solar system planets

— Measure chemical elements in the structure of comets.

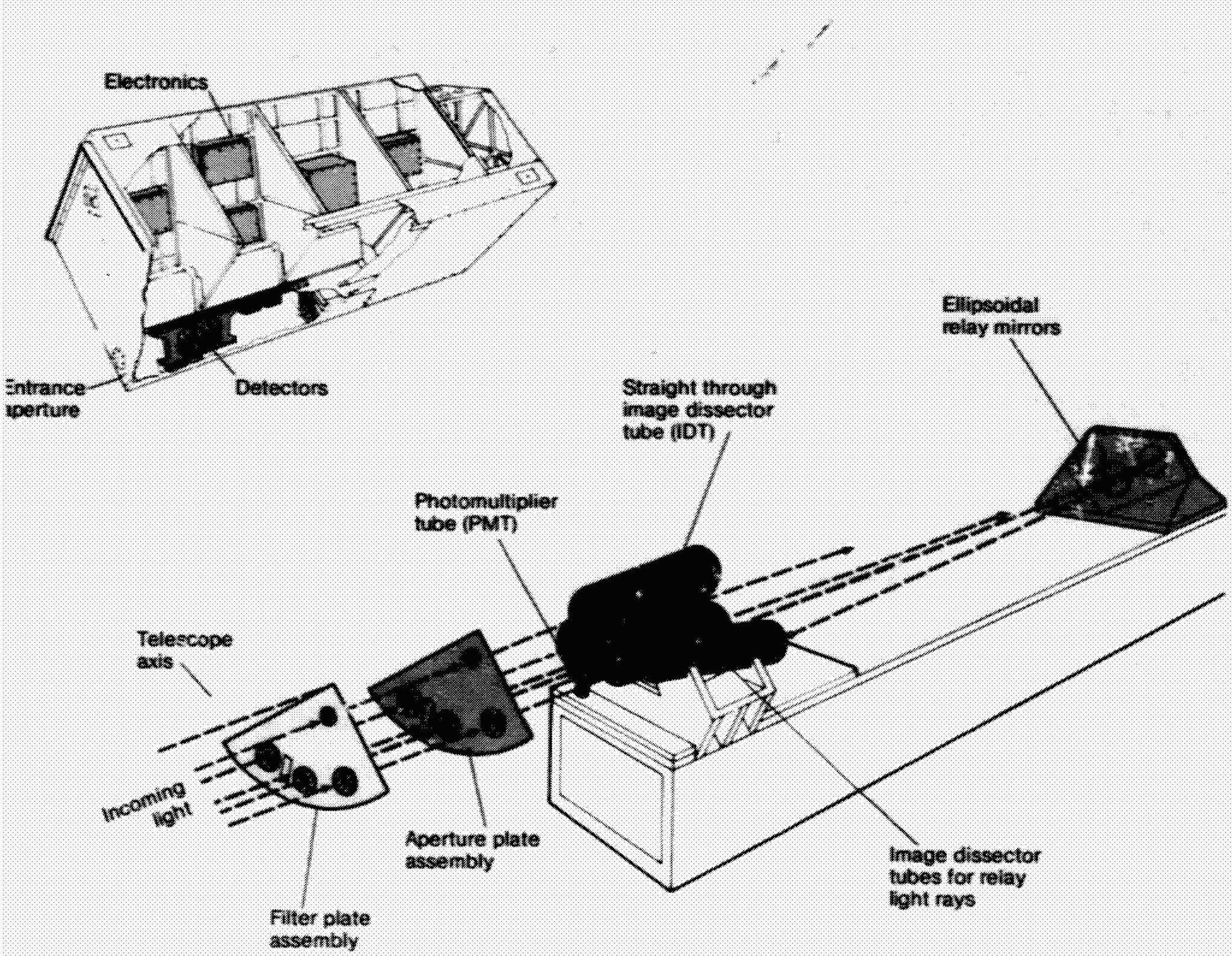
## *High Speed Photometer*

The High Speed Photometer is designed to provide accurate observations of the total light from an object in space, note any fluctuations in brightness on a time scale down to microseconds, and to detail any fine shapes or structures associated with the light source. These measurements are made over a wide spectral interval, including the ultraviolet.

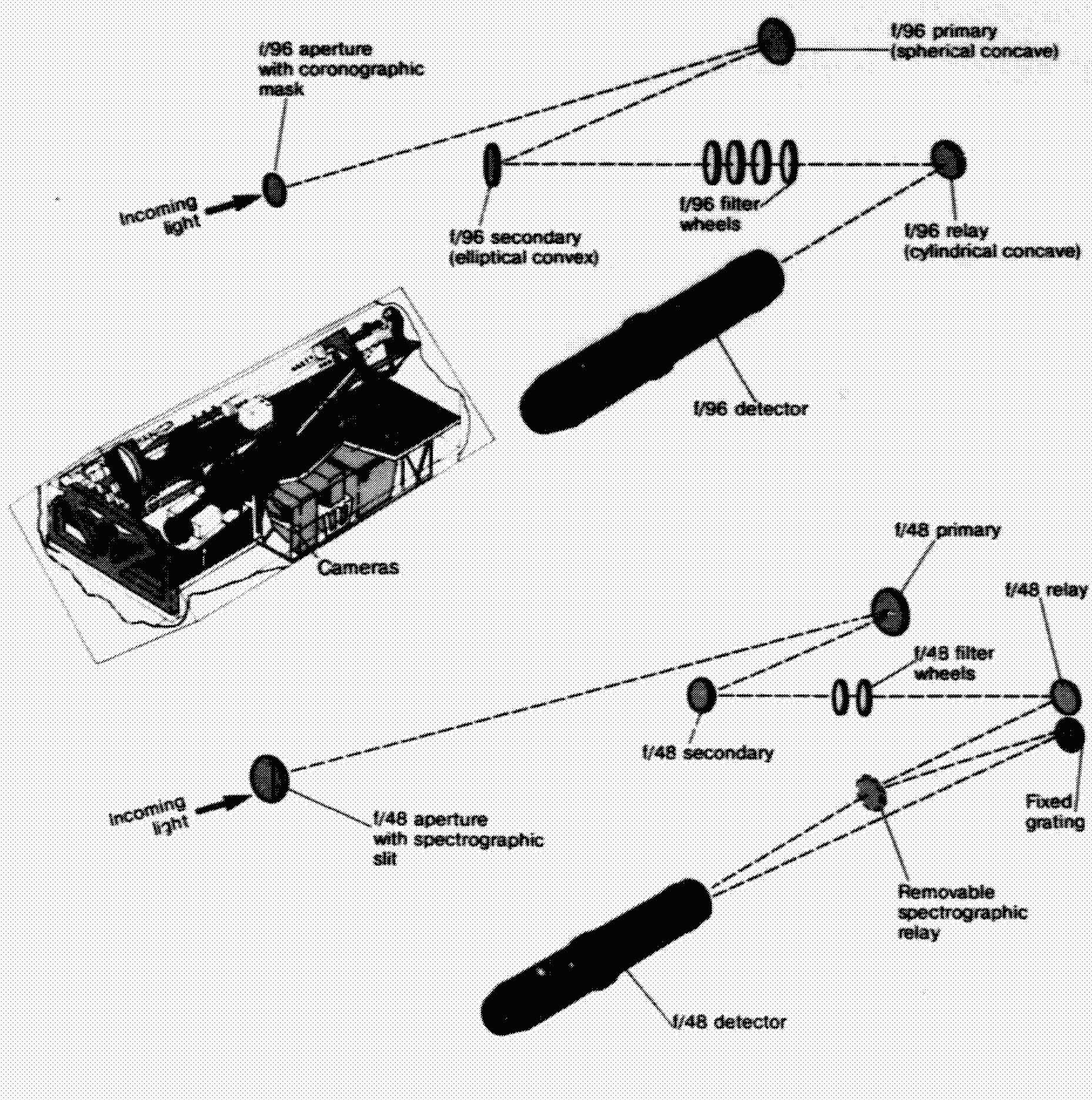
It is the simplest instrument of the group, containing no moving parts, and relies entirely on the pinpoint accuracy of the spacecraft's pointing capability to accomplish its job. After it receives the light from a star or other source, a detector measures the total brightness of the object or the intensity of light in a particular portion of the spectrum.

The High Speed Photometer, in addition, will transmit accurate information on fluctuation as a function of time. Detection of rapidly spinning neutron or other compact stars will be possible, also detailed data on the shape and structure of the fine spikes or flares often associated with such compact objects.

The instrument will be of special service to astronomers in establishing calibration standards for faint stellar objects. Because the brightness of the objects will be ascertained in fine detail, the relation of stars to each other and their distances from Earth will be established much more precisely than at present.




*High-Speed Photometer design concept. Approximately 100 combinations of filters and aperture pairs can be imaged on the detectors. Observations of rapidly varying astronomical sources can be time resolved on time scales as short as 16 microseconds.*




*(Top) Optical design concept for the f/96 mode of the Faint-Object Camera which will provide the highest spatial resolution images of any optical instrument in space or on the ground.*

*(Bottom) Optical design concept for f/48 mode of the Faint-Object Camera. This mode provides less spatial resolution than the f/96 mode but does deliver a larger field of view.*

The High Speed Photometer will be used to:

- Make precise observations of rapidly pulsing compact objects, exploding variable stars, and binary systems
- Examine properties of zodiacal light (sunlight reflected from solar system dust) from the Sun in the ecliptic plane, and diffuse galactic light
- Calibrate faint stellar objects
- Examine specific spikes or flickers of light ejected from stellar objects, including compact stars and supernovae, for shape and structure.

## *Faint Object Camera*

This instrument, being built by the European Space Agency, uses the spatial resolution of the telescope in order to capture images of very faint objects in the universe.

It is expected to be able to detect stars as faint as the 28th magnitude and will easily pick out stars of magnitude 24, which is about the best a large ground observatory can now do. Magnitude is a designation of brightness—the lower the number, the brighter the object. The dimmest stars the average person can see with the naked eye are magnitude 6. The brightest stars are magnitude 1. Venus is magnitude −4 (minus four).

The Faint Object Camera has a basic focal ratio of f/96 and is capable of observing faint objects or extended structures near bright sources. This device will have four filter wheels, each containing a variety of filters with 12 positions, that can be inserted in the optical path.

The system works by gathering and focusing incoming feeble starlight on an electronic image intensifier. The intensifier's output is scanned by a vidicon camera tube and an image consisting of 250,000 picture elements is obtained. An f/48 focal ratio camera system will permit the camera to operate in a spectrographic mode which is ideal for studying the structure and dynamics of the center regions of galaxies. It is suspected that these regions could harbor massive black holes. This mode of operation will employ fourteen insertable filters.

Exposure times of some very faint objects might run as high as 10 hours.

The Faint Object Camera will be used to:

- Observe extragalactic supergiant stars
- Study variable brightness stars
- Gather data on globular clusters
- Examine binary star systems
- Search for extrasolar planets
- Establish stellar masses
- Do detailed studies of shock fronts and condensing gas clouds
- Search for direct evidence that quasars might be at the center of faint galaxies.

## *Fine Guidance Sensors*

Because of the very high spatial resolution of the Space Telescope it requires extremely high pointing stability. This so-called sixth scientific instrument will be used primarily to provide this stability. Two sensors are sufficient for locating and locking onto a target. Meanwhile, the third can be used to view and precisely measure the positions of other stars in the vicinity in relation to the stars on which the other two sensors are locked.

The three Fine Guidance Sensors are expected to produce measurements ten times more accurate than can be done now from Earth. The sensors work through a complex system of mirrors and light detectors to locate the position of a star against the

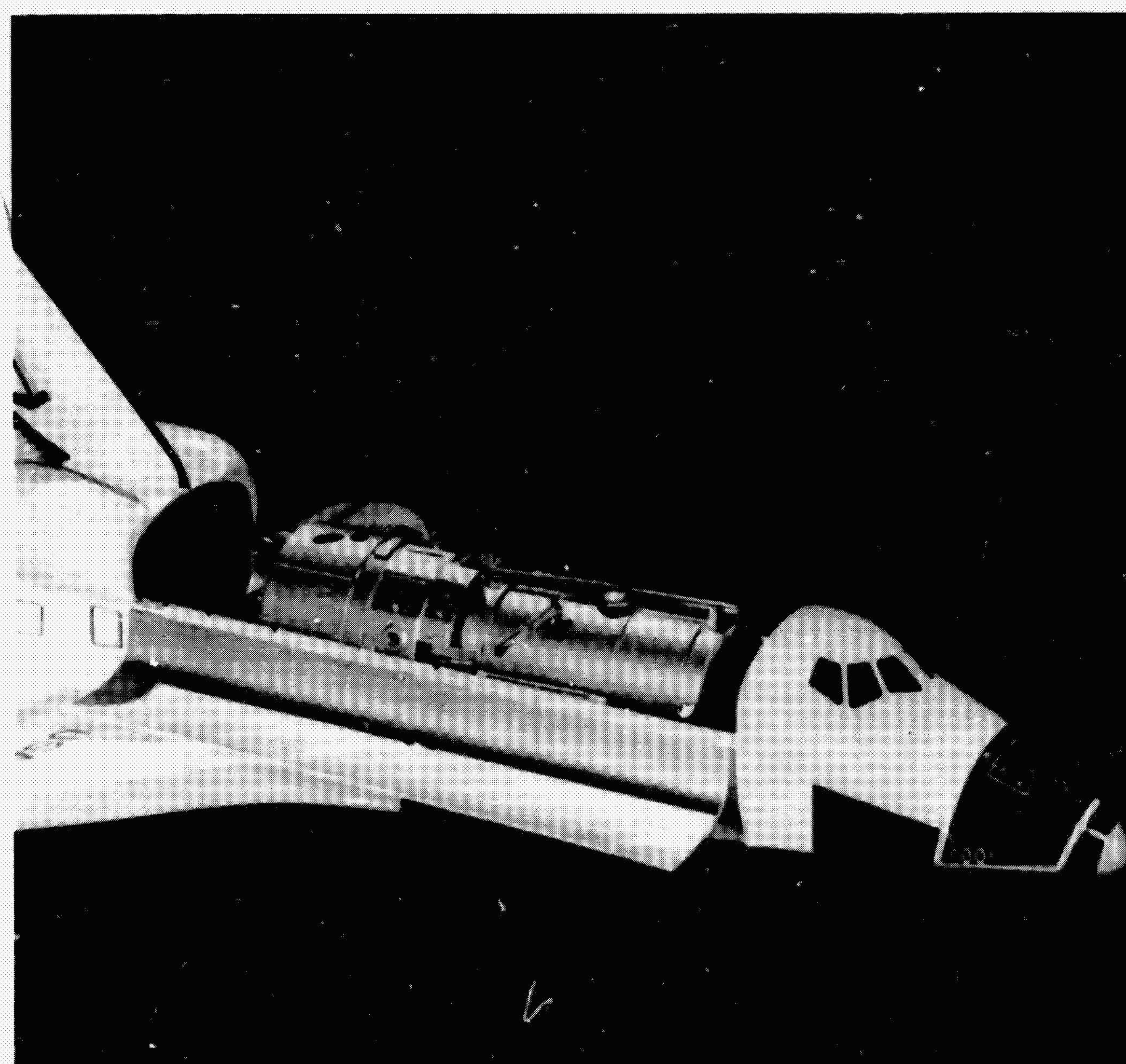
background of a number of stars. In measuring the distance to a star, ground controllers will have the sensors focus on a foreground star to transmit data on its position relative to the stars in its background. The objective is to measure the spatial distance between the foreground star and the background stars. Similar measurements are made about six months later and the shifts are compared. The differences will indicate the distance of the star from Earth.

Making precise measurements of star positions is called astrometry. Information provided by the Fine Guidance Sensors will assist in finding the answer to the open-versus-closed universe question.

The Fine Guidance Sensors will be used to:

- Provide stability to the satellite
- Calibrate the positions of nearby and distant stars and galaxies
- Reveal new information on the unseen companions of binary star systems
- Provide more accurate positional information on the satellites of Jupiter, Saturn, Uranus, Neptune, and Pluto
- Establish better positional reference systems on compact stars.

Space Telescope in its stowed position inside the cargo bay of the Space Shuttle Orbiter.



# Putting It Up, Making It Work



Putting the Space Telescope in orbit is the job of America's new Space Transportation System, the Space Shuttle.

Space Shuttle is a true aerospace vehicle that takes off like a rocket, maneuvers in Earth orbit like a spacecraft, and then lands like an airplane. Briefly, it is composed of an Orbiter, propellant tank, and launch boosters.

The Shuttle is designed to carry heavy loads into Earth orbit. Other launch vehicles are capable of placing large payloads in orbits, but unlike the other vehicles, which could be used only one time, each Space Shuttle Orbiter can be used over and over again. Three main engines and two solid rocket boosters provide the power to get the Orbiter off the ground and into space. Two onboard maneuvering engines position it in final orbit and a variety of small thrusters provide the necessary maneuvering capability.

The Orbiter is the crew-and-payload-carrying portion of the Shuttle system and is about the same size and weight as a DC-9 commercial aircraft.

Just behind the crew quarters is the cargo bay. The bay is flexible enough to provide accommodations for spacecraft in a variety of shapes and sizes—or for fully-equipped scientific laboratories. Payloads weighing as much as 29,250 kg (65,000 lbs.) can be carried in the 4.5 by 18 m (15 by 60 ft.) bay.

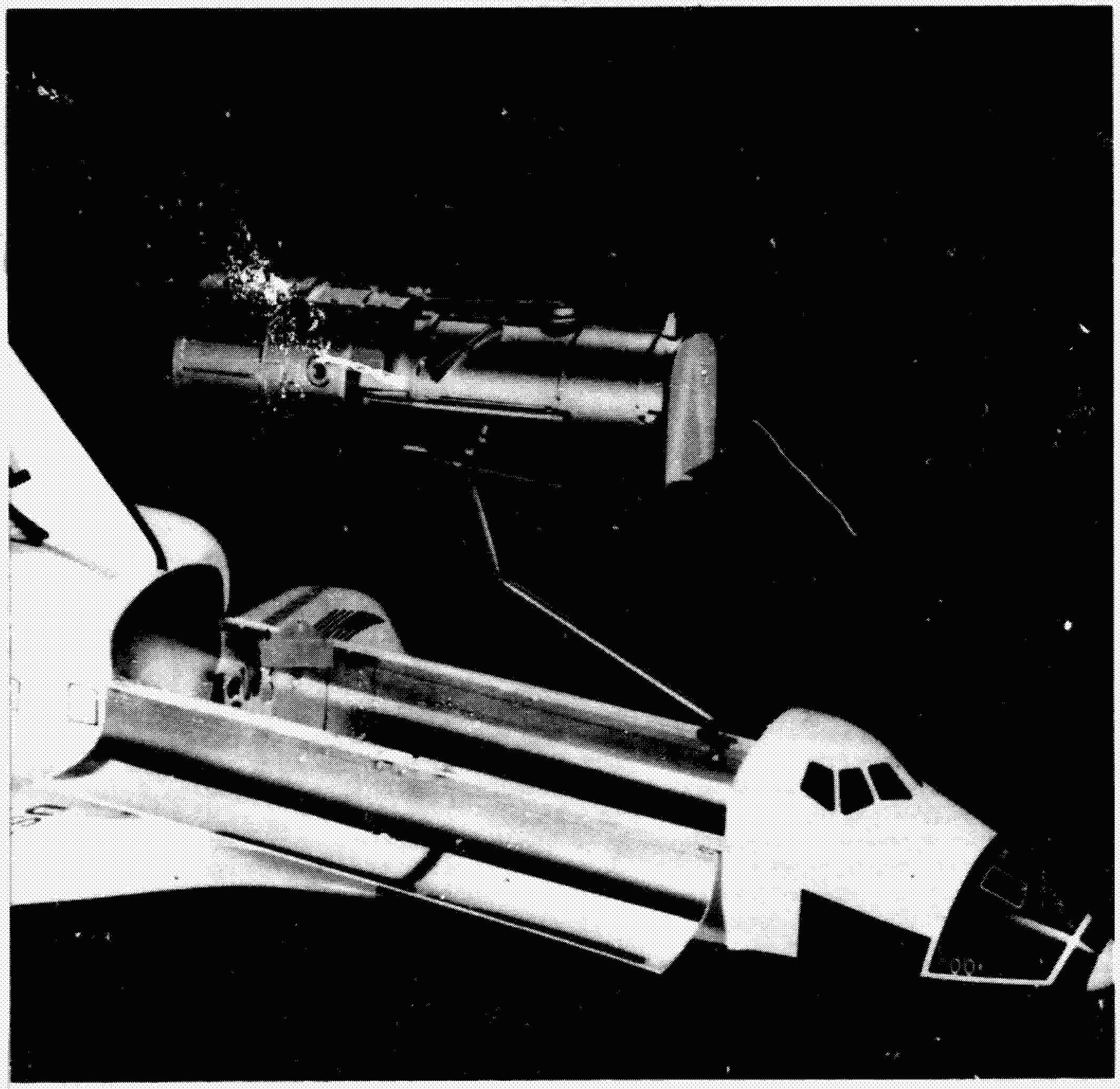
## On-Orbit Maintenance Provided

Space Telescope is a free-flying spacecraft designed for Shuttle launch and on-orbit maintenance. It can be serviced in orbit by the Shuttle and brought back to Earth for refurbishment. In this way it can be kept updated by having astronauts replace the instruments, batteries or other modules in flight or by ground maintenance when the entire spacecraft is brought back to Earth.

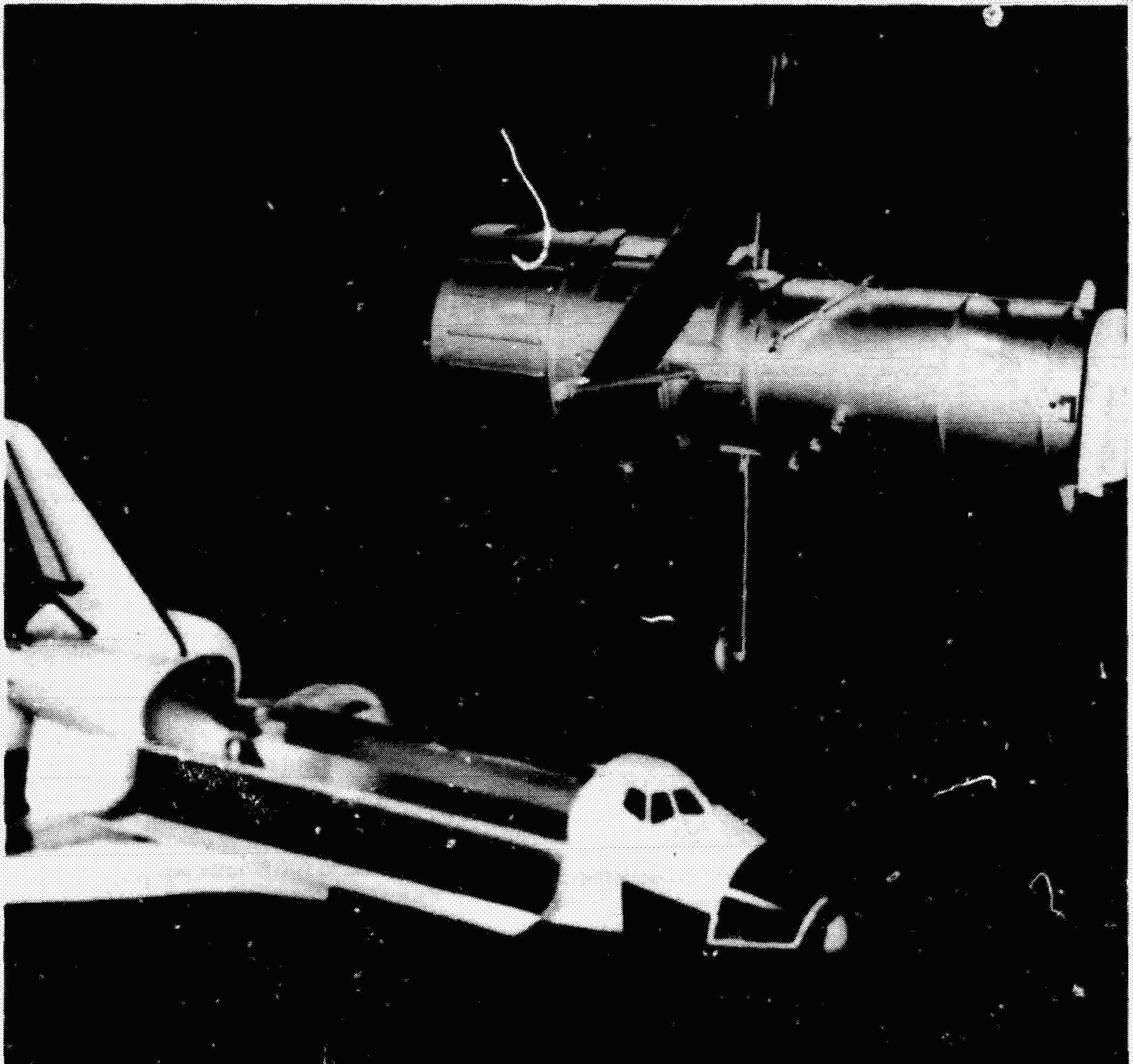
Space Telescope will be launched from Kennedy Space Center, Florida. The Shuttle commander will handle the maneuvering and attitude control aspects as the Orbiter attains the proper flight altitude. At this point, the cargo bay doors are opened and the crew readies Space Telescope for release into orbit.

The pilot electronically controls a 15 m (50 ft.) mechanical arm or Remote Manipulator System connected to the Space Telescope in the cargo bay, then moves it out of the bay.

Following release of the Space Telescope into free flight the Orbiter remains in the vicinity in a standby position. During this period checks are made from the spacecraft as various systems are activated and the solar panels and high-gain antenna are deployed. With these initial functions satisfactorily completed, a number of subsystems on the telescope are turned on and checked



*Space Shuttle Orbiter's manipulator arm removes Space Telescope from the cargo bay, before releasing it into Earth orbit.*



*Space Telescope, with solar panels and antenna booms extended in Earth orbit (with Space Shuttle Orbiter remaining in its vicinity to complete final checks on its operational status).*

out. When the ground controllers at NASA's Goddard Space Flight Center are satisfied that the satellite is functioning properly, the Orbiter is free to return to Earth or go on to some other task.

For on-orbit maintenance missions the Orbiter will rendezvous with the Space Telescope. When the Orbiter's flight path has been matched precisely with that of the telescope and rendezvous in orbit is accomplished, the manipulator arm will lock onto the free-flying telescope, bring it into the cargo bay, and stand it upright on a maintenance platform.

Because Space Telescope engineers anticipate a gradual "decay" of its orbit, caused by atmospheric drag, the Shuttle Orbiter may reboost the Space Telescope back up to its proper initial orbit. There, the Orbiter crew will begin the required maintenance.

The pilot and mission specialist will don space suits and crawl through an airlock from the crew compartment into the bay. No more than two crew members will be outside the Orbiter crew compartment at any one time and extra-vehicular activity (work away from or on the exterior of the Orbiter) will not exceed 6 hours in any 24-hour period.

## *Spare Parts Available*

During the two 6-hour work periods, the crew members will have available spare components, replacement parts or new modules that have been stowed in a special structure in the cargo bay, called an environment protective enclosure. The structure also serves as a work station for the two crew members who will be able to move to various parts of the spacecraft, replacing or repairing as necessary. In order to make the job easier for the work party, the telescope will be tilted toward the work station or positioned on the maintenance platform as necessary.

Work aids such as tethers, equipment transfer devices, foot restraints, rails, handholds, and lights will be used. Foot restraints are considered the most important aids for working on the spacecraft as they leave the hands free and establish a fixed reference point for astronauts or technicians. In areas where there are no foot restraints, portable restraints can be mechanically attached.

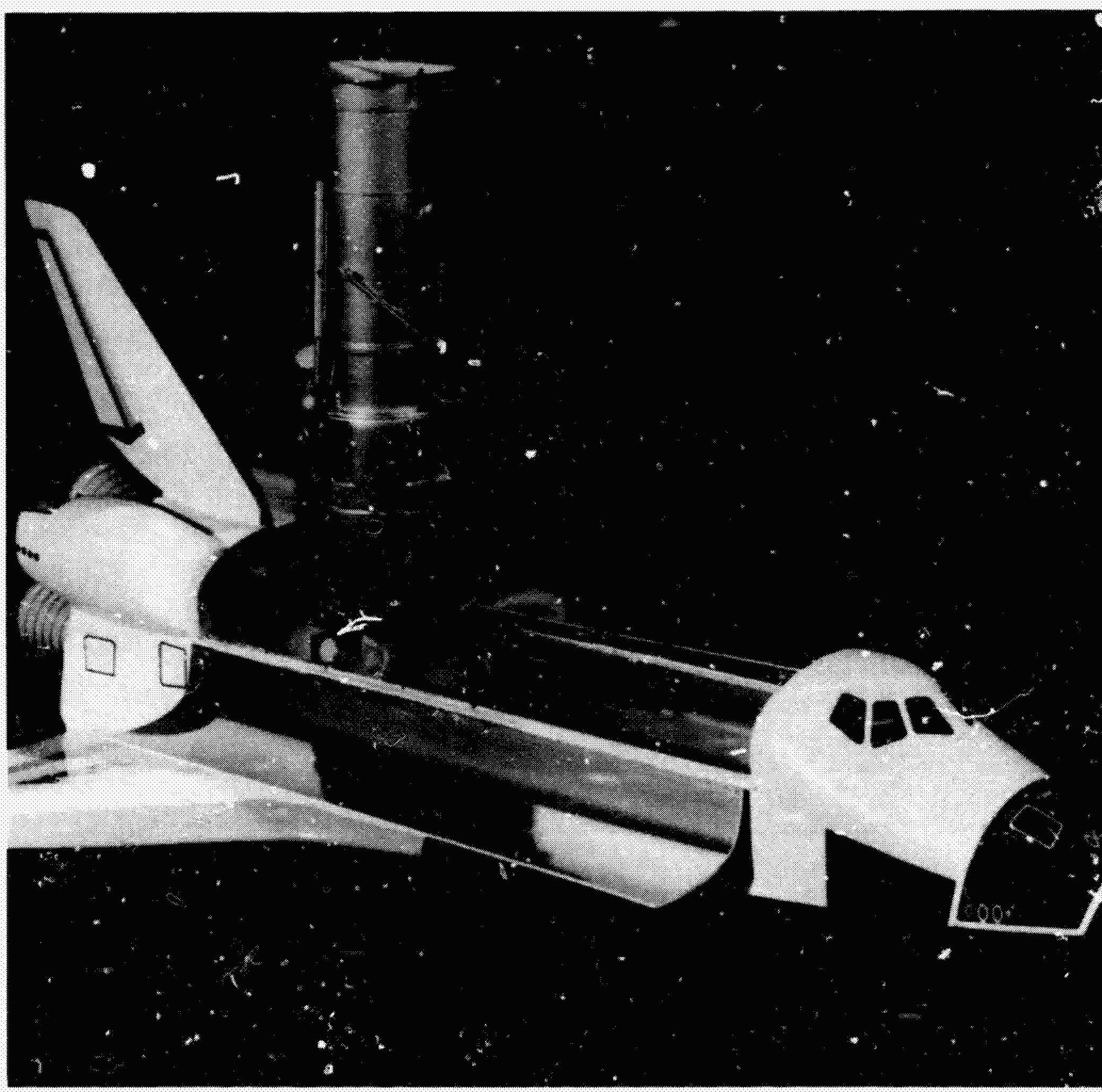
After on-orbit maintenance has been accomplished, the two-astronaut team will return to the cabin for testing. An expert on the flight deck will work with the crew to make sure that all circuits, mechanisms, and instrumentation test satisfactorily. Ground controllers will also participate in the checkout.

When everything appears to be in good working condition, the telescope will be moved out of the cargo bay by the manipulator arm and again placed in orbit. The Shuttle Orbiter will remain nearby while the spacecraft's solar panels are redeployed and a final in-flight checkout is accomplished.

Maintenance activity in space is not a new concept. Unplanned maintenance tasks were performed during four Skylab missions in the 1970s. Such tasks included solar array repair and replacement of faulty gyroscopes.

The refurbishment process, depending on need, could involve disassembly of major elements on the ground for extensive overhaul. Replacement of Space Telescope's major components, including work on the mirrors, would require returning it to Earth but exchanging much of its other equipment could be done on orbit.

Major ground refurbishment is expected to take as much as 2½ years to complete. This would include re-assembly and relaunch by Space Shuttle.



*Space Telescope in a vertical position relative to the deck of the Space Shuttle Orbiter's cargo bay — ready for on-orbit maintenance.*

*Astronauts work on Space Telescope outside Space Shuttle Orbiter's cargo bay. Each component or instrument that will be replaced is designed with simple locking devices which allow for quick disconnect of cables and mounting restraints.*

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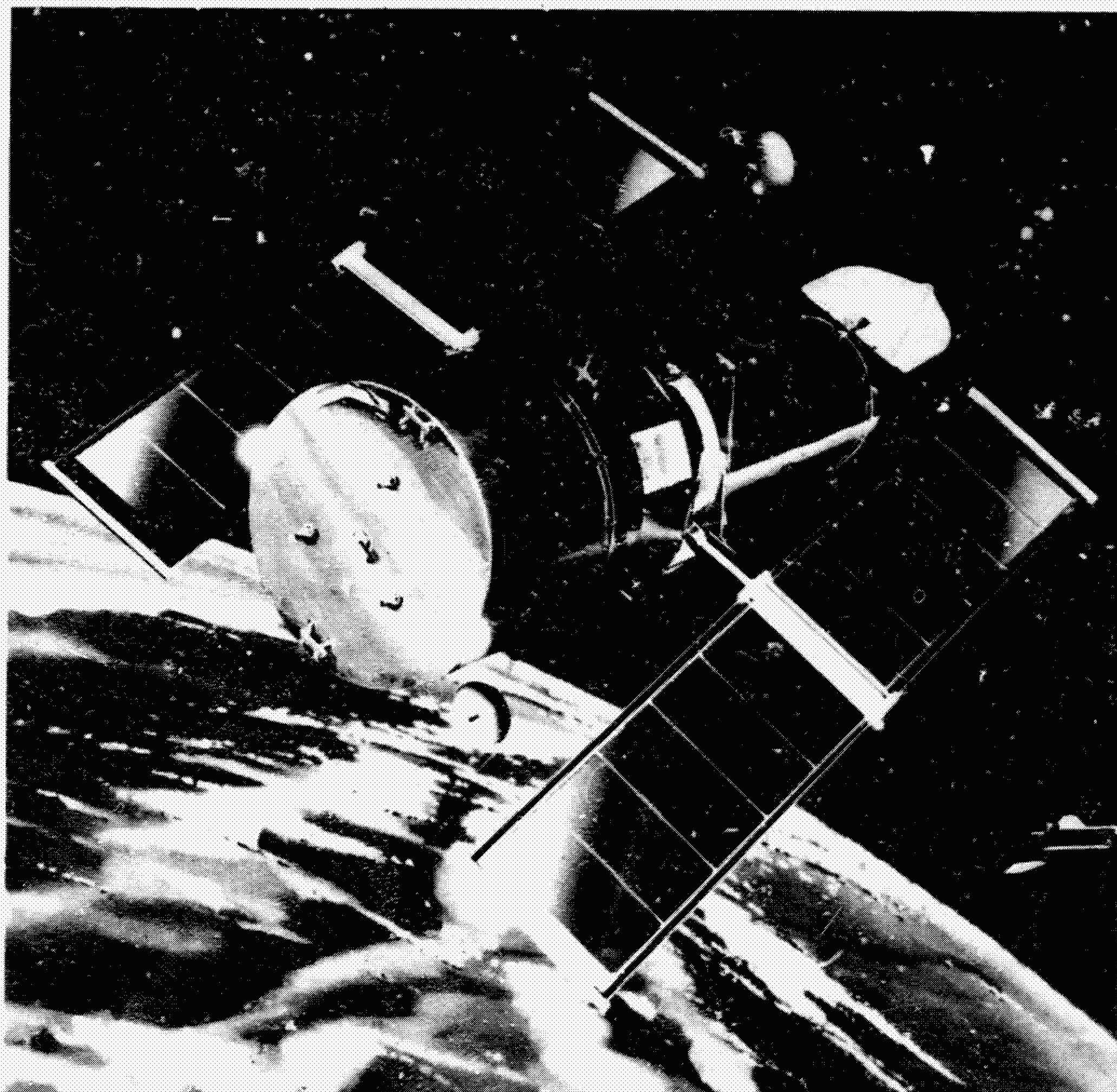


*Artist's concept of Space Telescope in Earth orbit — with the Shuttle Orbiter in its vicinity.*

# The Space Telescope Science Institute

To place the responsibility for obtaining scientific results in the hands of the scientific community, NASA has established and is funding a Space Telescope Science Institute to be managed by the Association of Universities for Research in Astronomy (AURA).

Members of the AURA consortium are: University of Arizona, California Institute of Technology, University of California, University of Chicago, University of Colorado, Harvard University, University of Hawaii, University of Illinois, Indiana University, Johns Hopkins University, University of Michigan, Massachusetts Institute of Technology, Ohio State University, Princeton University, University of Texas, University of Wisconsin, and Yale University.

The Institute facility itself is located on the Homewood Campus of Johns Hopkins University, in Baltimore, Maryland. NASA will oversee the operation of the Institute and see that the scientific objectives of Space Telescope are met.

To achieve these objectives, the Institute will solicit and select observational proposals from astronomers, as well as coordinate research and international participation. It will determine viewing schedules and the availability and sequence for observing various space phenomena, in cooperation with the Space Telescope's Payload Operations Control Center at the Goddard Space Flight Center, Greenbelt, Maryland.

Collection and reduction of telescope data will be a prime function of the Institute. Data analysis will be accomplished by principal investigators, general observers and archive researchers from a variety of organizations and universities, who will analyze their own data as it becomes available. Scientists on the Institute staff will also conduct analyses, do basic research and disseminate data to the science community. An Institute archives section will store all data received.

When it is functional, the new organization will have a staff of about 200 persons, including about 35 scientists, and will be directly tied in with the operations center at Goddard in receiving and processing data. European Space Agency scientists will be participating in the activities of the Space Telescope Science Institute.

## TDRSS to Return Data

Data from the telescope will ultimately be transmitted via the Tracking and Data Relay Satellite System (TDRSS) to a ground station at White Sands, New Mexico. From the station, the data will be transmitted via a commercial communications satellite to Goddard Space Flight Center where standard processing and "packaging" operations are performed. The data will then be sent via land line to the Institute where an observer may get both finished or calibrated data, or the original raw material received from the orbiting telescope.

Selection of observers will be one of the big tasks of the Science Institute, assisted by outside reviewers.

An average of at least 15 percent of the

observing time will be allocated to scientists from member nations of the European Space Agency. This is in recognition of that organization's contribution of the Faint Object Camera, solar arrays, and operations personnel at the Science Institute.

Selection of telescope users will be based on judgment of the importance of their proposals and the feasibility of accomplishing the goals. It is expected that requests for use of the new space observatory will far exceed operating time available on the telescope.

To achieve the best technical and professional results, observing proposals will be submitted by potential users. The Institute staff will examine these proposals for technical feasibility, then ask an external science peer group to evaluate them for scientific quality.

New proposals will be submitted and reviewed throughout the lifetime of the observatory, with periodic announcements of observer selections. NASA, through the Space Telescope Science Institute, will provide funding for observers from the United States. Those selected from other countries will provide their own funding.

## *Schedule Adjusts to "Opportunities"*

Targets of opportunity, such as the discovery of a supernova or unexpected success by an observer in acquiring an object such as a flaring star, will require adjustments in schedules for the use of the telescope.

Secondary observations in addition to those scheduled involving the Wide Field Camera and a single additional science instrument may be scheduled when targets of opportunity are encountered—to exploit any "serendipitous" discoveries.

Normally, Space Telescope scientists will have exclusive rights to their data for one year. In cases where the nature of the data takes more than a year to reduce and analyze, special exemptions can be made.

The general policy for the Institute will be that all data obtained through the facility will be cataloged and placed in its archives. The archives will be available to the world scientific community. Members of the public may also obtain information on request.

# Astronomy Enters The Space Age

In the Space Age, a variety of satellite and sounding probes have been used to directly observe space phenomena, but such observations have been made primarily in non-visible spectra. Data returned in ultraviolet, infrared, x-ray and other regions of the spectrum whose radiations cannot reach Earth, have detected intriguing new phenomena in the universe. But, compared to Space Telescope, these earlier spacecraft have returned only glimpses of what awaits us in 1985.

Modern astronomy isn't concerned solely with looking at stars and observing planetary motion. All scientific disciplines are involved because of the wealth of information that is being returned in all fields.

We now know that *all* types of radiation are emitted from the billions of stars, galaxies, and mysterious objects that make up the cosmos. The light we see is only a small part of the total spectrum of energy radiations. These include infrared, ultraviolet, radio waves, x-rays, gamma rays, and cosmic background radiation.

## *Many Sciences and Technologies Involved*

Computer technology, nuclear physics, chemical analysis, photographic and optical technology, plasma physics, particle physics, electronic engineering, geophysics, life sciences, and many other sciences and technologies are necessary to examine this vast new extraterrestrial realm. Such exotic phenomena as pulsars, quasars, neutron stars, black holes and other mysteries of our universe demand an interdisciplinary approach.

Recent Solar System explorations by automated spacecraft have raised many questions about the possibility of life in our Solar System and the evolution of the planets, including Earth. Exploration of the Moon, including astronaut landings on its surface, has given geophysicists and geologists first-hand material to study. Photos and data from Mercury, Venus, Mars, Jupiter, and Saturn raise questions about planetary processes, and tell us much about our place in the Solar System.

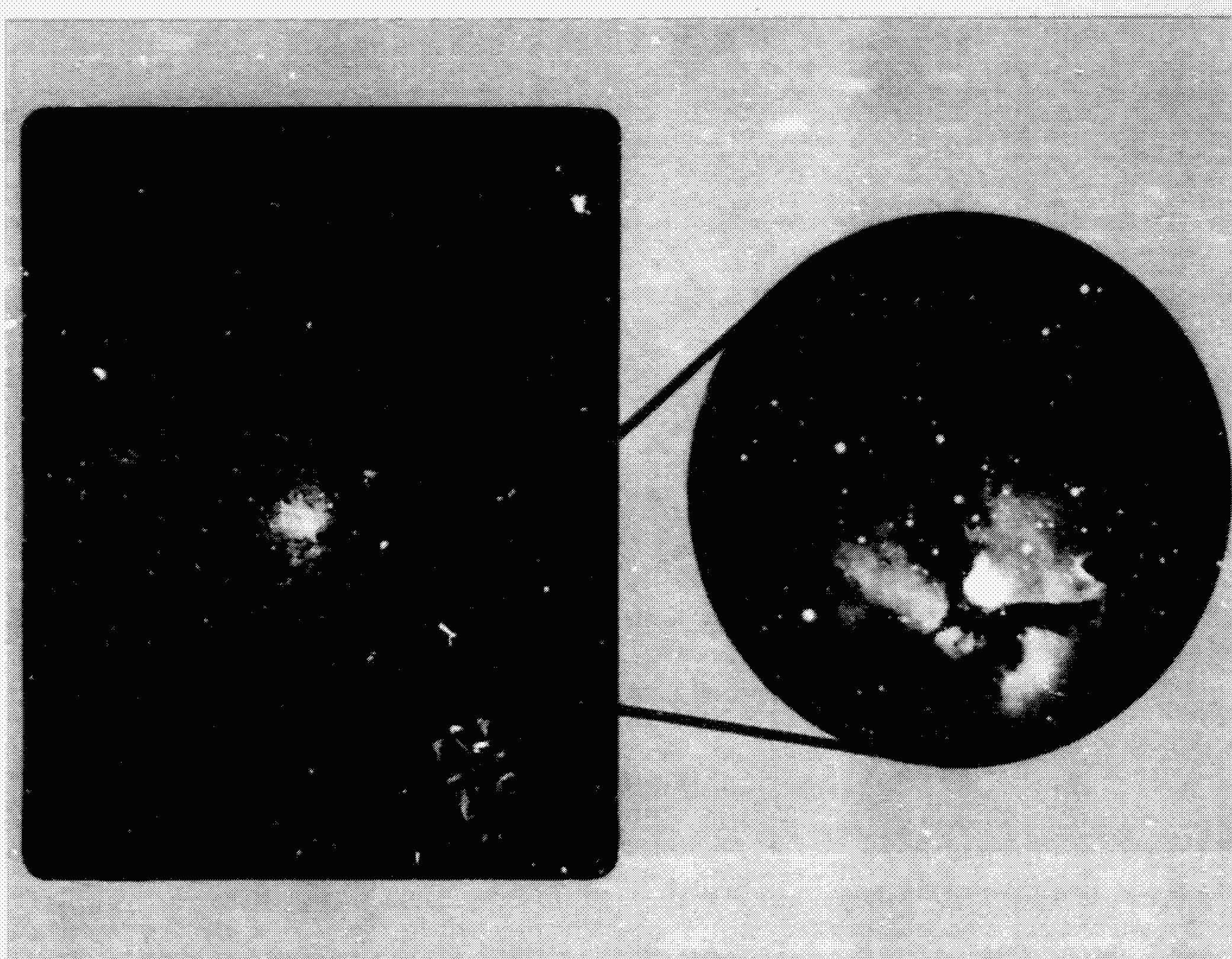
Who, before the Age of Space, would have suspected that Venus had an atmosphere so hot it would melt lead?—that Mars once had great rivers flowing through huge canyons and boasts the largest volcano that has been seen in the solar system?—or that mighty Jupiter has a satellite, Io, with active volcanoes or eruptive plumes?

Astronomy has always been in the forefront in stimulating human curiosity and imagination. Since earliest times when our ancestors first gazed at the skies, men and women have wondered and steadily increased their knowledge.

We are still at the beginning of our quest to understand the universe. The Space Telescope will tell us much but, as old questions are answered, new ones will replace them a thousandfold.

# *Some Things Space Telescope Will See*





**A SECTOR OF THE NIGHT SKY** *(above, left) as it appears to an Earth-based telescope.*

**HOW THE SPACE TELESCOPE** *will view the very small circled area appearing in the picture at the left.*

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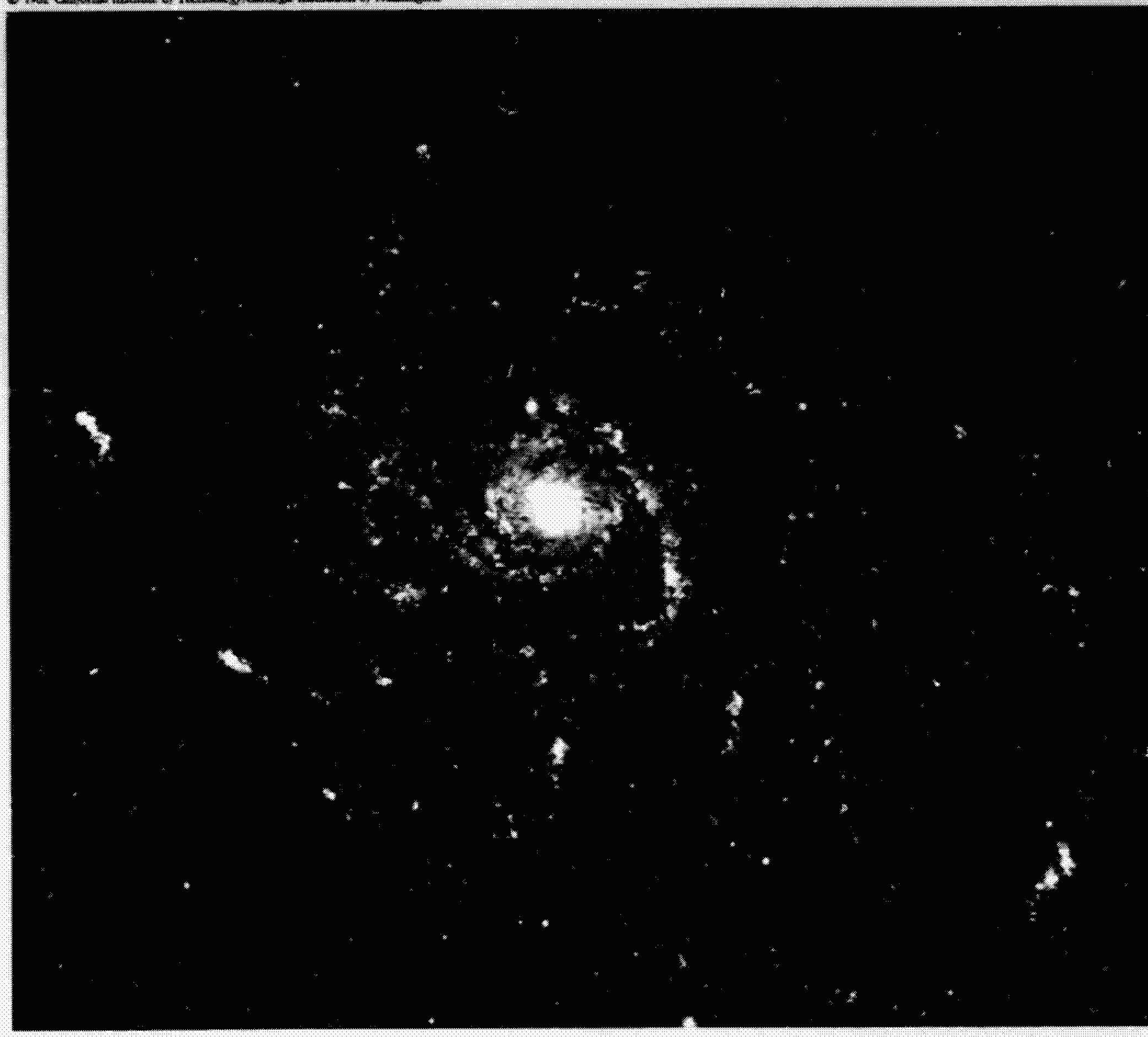

**SPIRAL GALAXIES** *are formed from more rapidly rotating clouds of primordial hydrogen gas than the elliptical galaxies. In the case of the more rapidly rotating clouds, some of the gas is drawn to the center to condense into stars. The remainder of the gas rotates around the center, slowly forming new stars. Such a rotating disk is unstable, forms arms and gives the galaxy its spiral shape.*

*Spiral galaxies have a bright center with the spiral arms extending outward. The nucleus is often brighter than the arms which may appear quite faint in telescope pictures. Although the disk may be about 100,000 light years in diameter for a typical spiral, its thickness often measures about 2,000 light years.*

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**ELLIPTICAL GALAXIES,** *which far outnumber spiral galaxies, have a nearly spherical or oval shape. They are often somewhat flattened, lack the spiral arms and are usually composed of nothing but stars. The gas clouds that give birth to stars condense quickly into stars, causing star formation soon after galactic birth by using up the dust and gas clouds at an early stage. Ellipticals contain many old stars and have a much greater range in size and brightness than spiral galaxies.*

*The smallest ellipticals are no larger than small groups of stars, globular clusters in our Milky Way. However, some of the ellipticals dwarf our galaxy, with diameters of 300,000 light years and are 100 times "heavier" than our galaxy. These are the largest, most massive accumulations of matter known in our universe.*



**IRREGULAR GALAXIES** *are usually smaller than spiral galaxies and present no regular structure. They do not have a typical bright nucleus or special appearance and include different types of stellar objects such as young and old stars, clusters of stars and variable brightness stars.*

*The Magellanic clouds, two of our three closest galactic neighbors, are irregular galaxies and show no special structure but contain binary stars, variable brightness stars, enormous numbers of giant stars—a half million or more in just one region alone—and many supergiants.*

*In some cases, irregular galaxies appear to have been disturbed by tremendous explosions somewhere in their interiors.*

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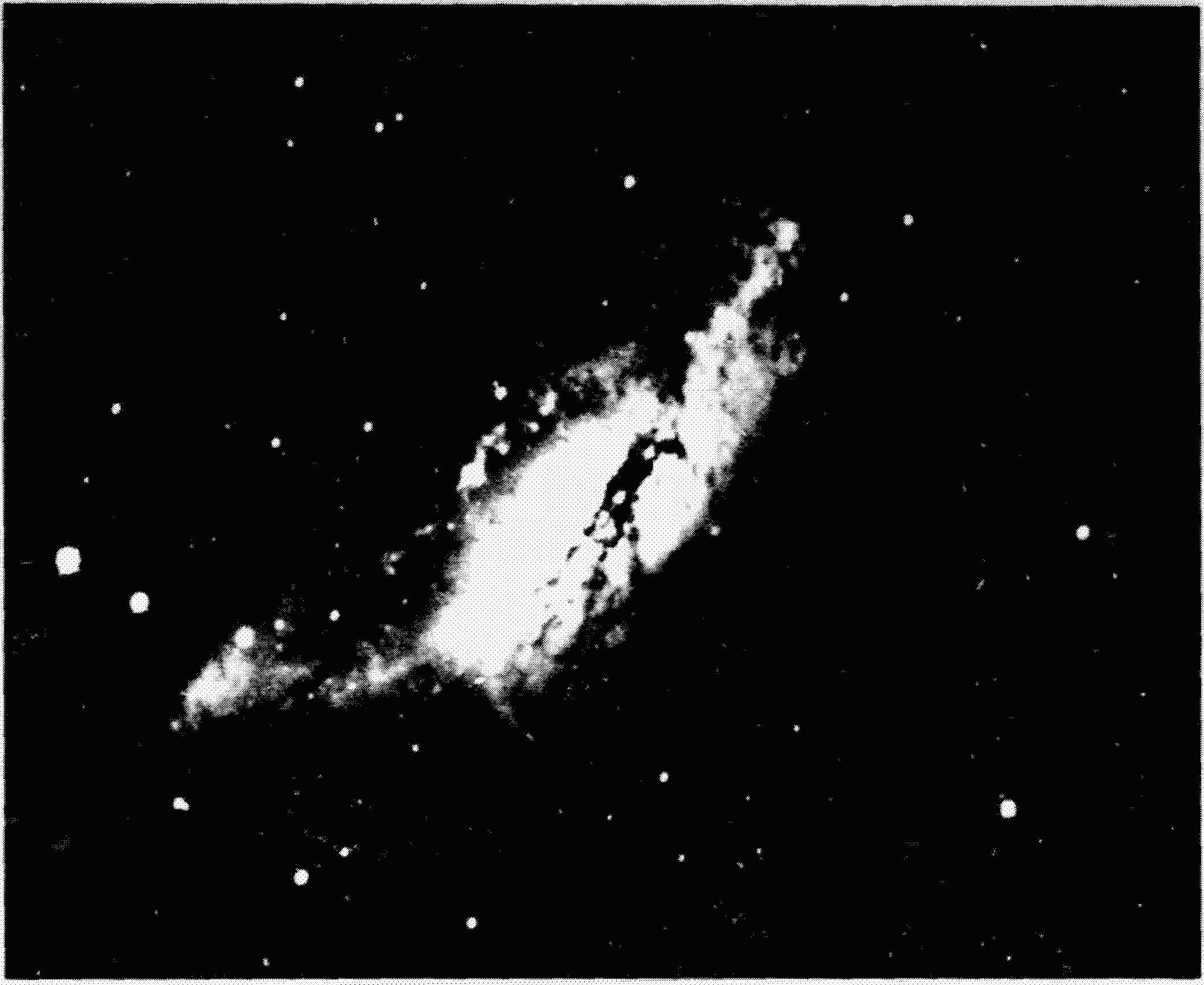
**GLOBULAR CLUSTERS** *are immense spherical groups of stars and are among the oldest groups (up to 13 billion years) in our Milky Way galaxy. There are 10,000 to 10 million stars in each cluster, itself a sphere about 100 light years across.*

*There are at least 125 globular clusters believed to be orbiting in a halo around the center of our galaxy, but they are located well away from the galactic plane.*

*When the galaxy was formed, these clusters of stars probably emerged early as the huge cloud of gas contracted to begin forming the billions of stars we see today.*

*Scientists believe there may be enormous black holes at the center of some of the clusters in our galaxy. Other galaxies have been observed to have similar globular clusters, also moving on elliptical paths around their centers.*



**ACTIVE GALAXIES** *exhibit a very bright center, many measuring about one light year across. Surrounding the core of the galaxy are huge, hot gas clouds moving at tremendous speed, hundreds of kilometers per second, indicating continuous explosions. The clouds are apparently heated and ionized by mini quasars which may emit less energy than a normal quasar.*

*There are more tenuous gas clouds filling the rest of the nucleus, which may measure from 100 to 1,000 light years in diameter.*

*Radiation emission from the core is mostly in the blue portion of the spectrum as well as in ultraviolet, infrared, and sometimes in radio waves.*

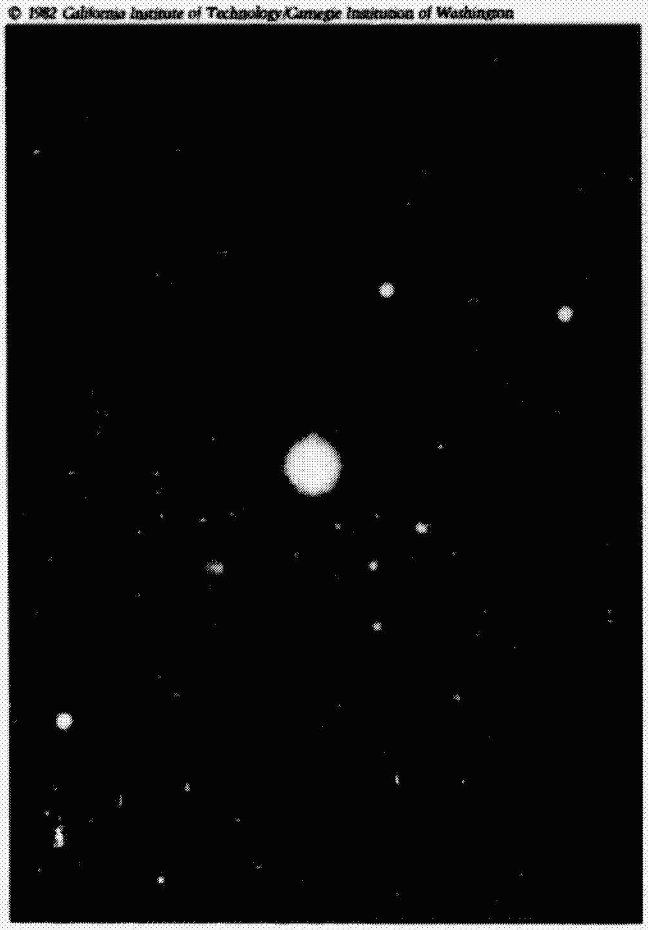
*Light brightness of the core varies over a number of months and in some exploding galaxies the amount of infrared radiation varies greatly. The infrared radiation emission is often greater than the entire output of visible light from the entire galaxy.*

**RADIO GALAXIES** *are enormous and emit extremely powerful radio waves a million times more powerful than those coming from our Milky Way.*

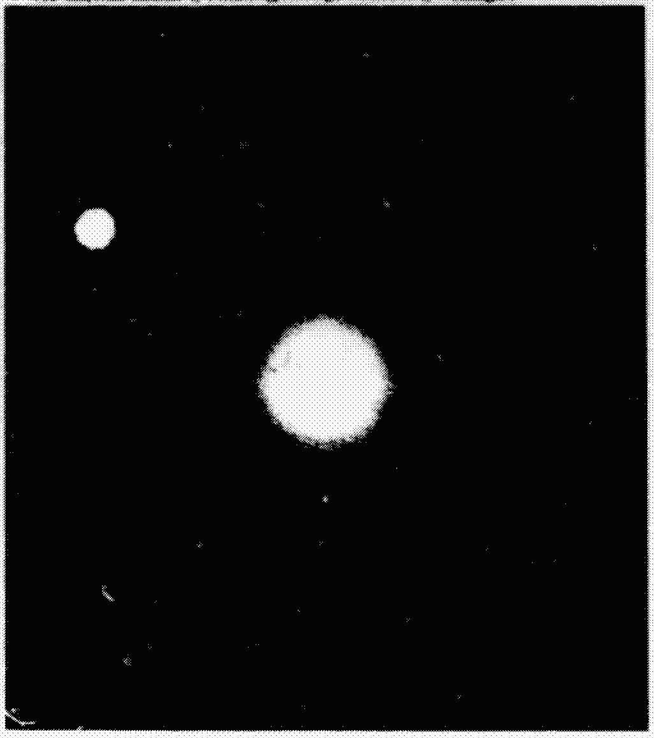
*What generates these emissions is not the galaxy itself, but two huge clouds on either side. Each cloud in the largest radio galaxy known is calculated to be 20 million light years long.*

*When first discovered, it was thought that such galaxies were actually two galaxies approaching each other, with the radiation coming from the gas cloud collisions. It later became clear that these were really enormous elliptical galaxies containing some 10 trillion stars in a volume somewhat spherical and often 500,000 light years across.*

*A small, very bright nucleus is at the center of some radio galaxies. This nucleus often produces as much light as all the rest of the galaxy's stars. It is known as an N-galaxy to indicate the brilliance of the nucleus.*







**A NOVA** *is a star which suddenly brightens and becomes visible in an area where it had not been seen before. Thus this type has been called "nova," meaning new.*

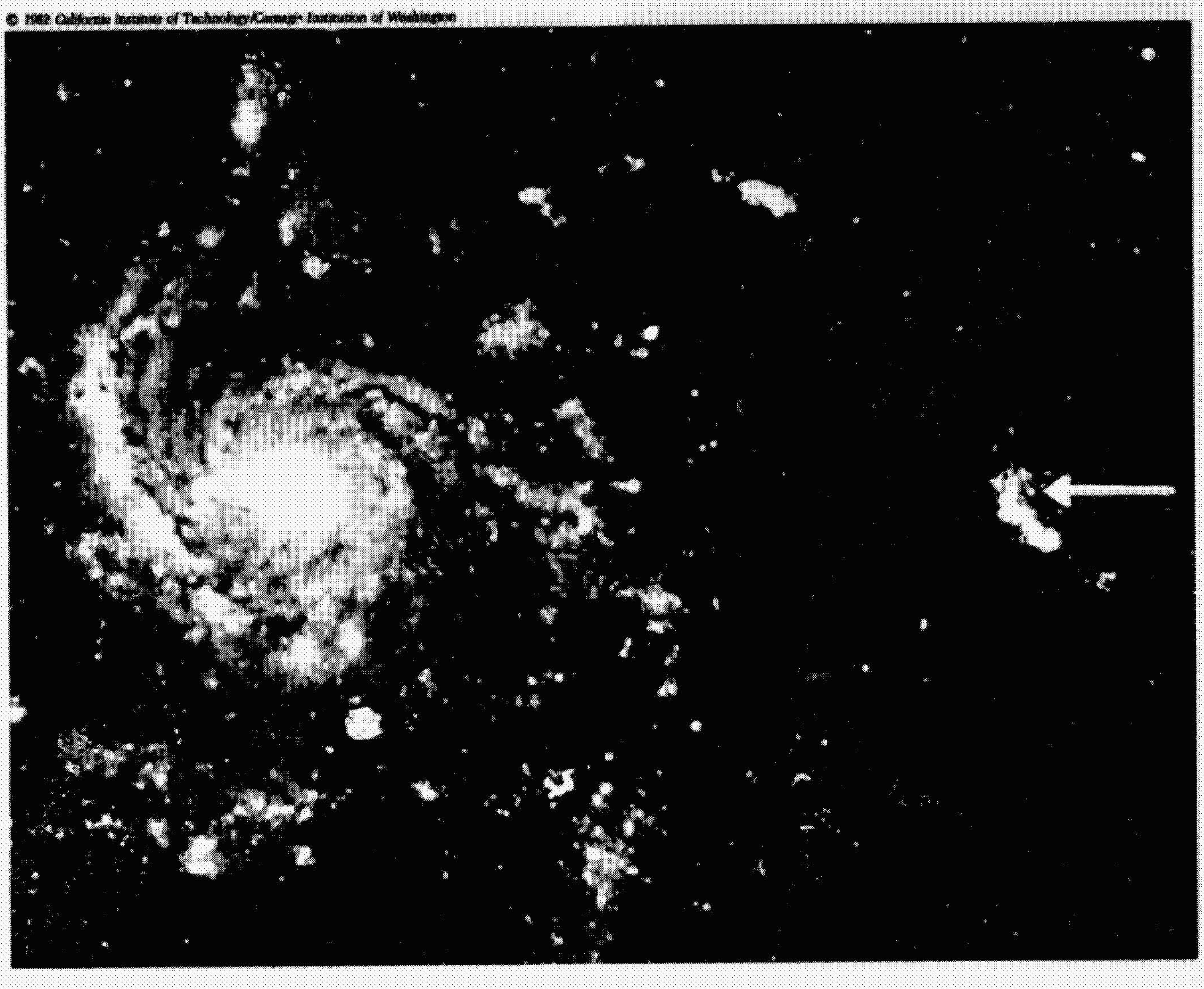
*The increase in brilliance is rapid, often occurring within a day or so and flaring up to a brightness thousands or even tens of thousands of times beyond its former radiance. After the initial flareup such stars usually fade over the following days, months or years.*

*Gas is blown off the star at very high velocity in what appears to be a large mass. The amount of mass ejected is only a tiny fraction of the star's total mass and the explosion has little effect on the star. Astronomers believe that almost all novae are parts of binary star systems, where gas from one star is drawn onto the surface of a white dwarf star. This causes a nuclear explosion when the gas ignites and is ejected into space.*

**QUASARS** *have been identified since the first one was discovered in 1963. These extremely powerful objects remain a mystery to scientists. Astronomers see them as star-like points of light that emit more energy than even major galaxies.*

*If quasars are as far away as many astronomers believe, they may be situated on the very "edge" of our universe. Certainly they are hundreds of millions, even billions of light years away. It is believed that if they are so bright at such vast distances, they must be at least 100 times more luminous than the brightest galaxy. This luminosity for many quasars changes, often in just a few months, by brightening or dimming by as much as 50 percent. Thus it is calculated that the region that emits the light must be very small in comparison to a galaxy, about one light year in diameter or one hundred thousandth (1/100,000) the size of a galaxy.*

*The amount of energy being released staggers the imagination. It is believed that the total energy emitted by a typical quasar in one second is enough to supply all of the electrical energy needs for our planet for the next billion years. Scientists continue to wonder about how such tremendous amounts of energy are generated.*



**SUPERNOVAE** *(see arrow) are massive stars at least five times the mass of the Sun. They have been known to explode, throwing out up to two solar masses at velocities of from 12,000 km (7500 mi) per second to 8000 km (5000 mi) per second.*

*During the explosion sequence, a supernova can expend as much energy as it did during its entire lifetime, often becoming as bright as a galaxy for a few days before fading away over the next few weeks. Depending on whether it has destroyed itself entirely by flinging all its mass into space or whether a dense central core remains, the explosion will either result in a gigantic dust cloud or merely leave the lone star's core.*

*If a dust cloud remains, a new star or stars may eventually form from its dust and that of other interstellar clouds. If a dense core remains, it may become a neutron star or black hole. Supernova explosions occur when the great mass of a large star collapses on itself.*

*These immense stars apparently evolve in less than 100 million years.*

ORIGINAL PAGE
COLOR PHOTOGRAPH

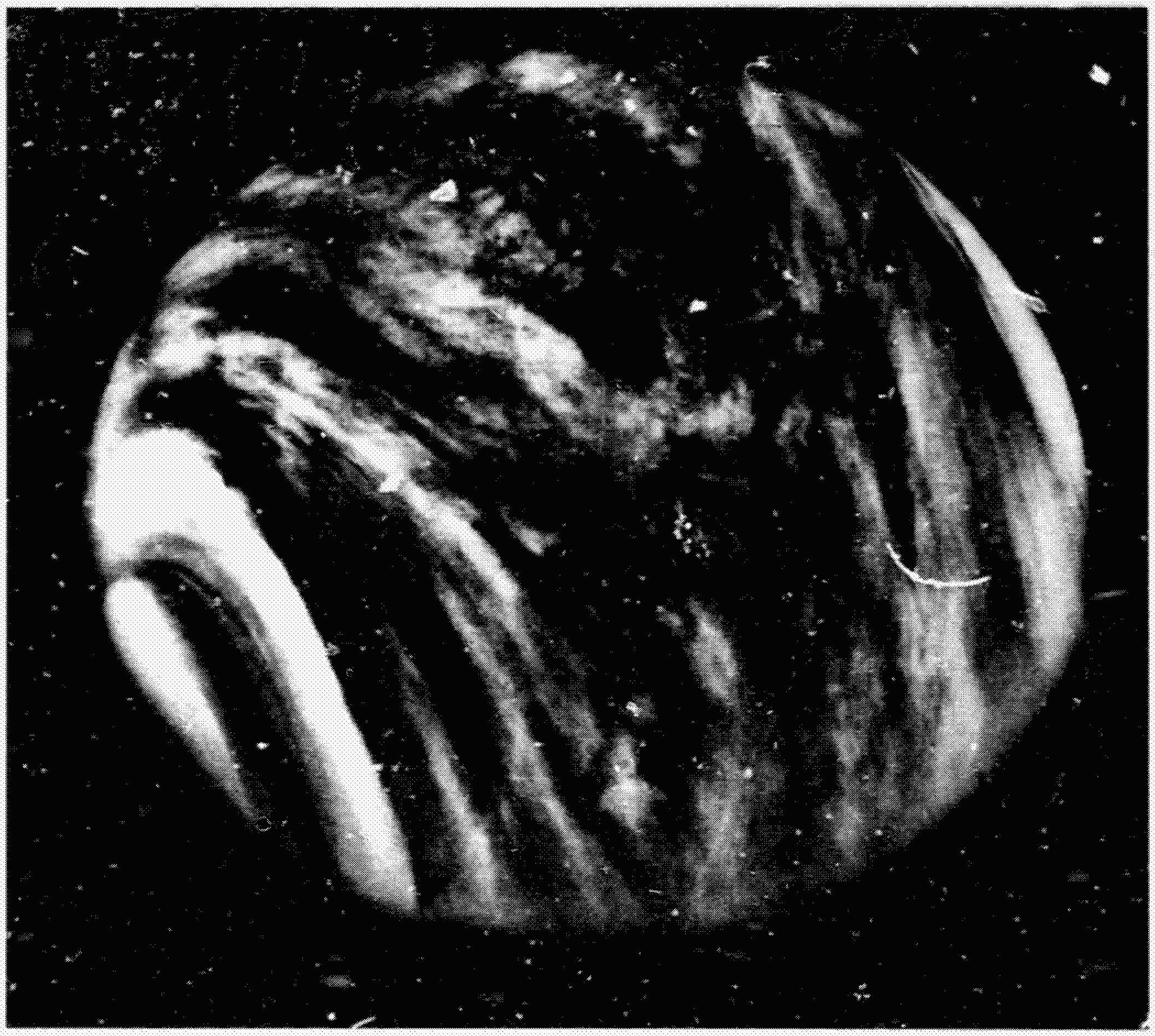


**PULSARS** *were discovered in 1967 when a radio astronomer first picked up their radiation, coming in flashes about once every second like those from a lighthouse. Because the pulsing source seemed so regular, even artificial, some observers speculated that the intermittent radiation could be signals from some form of extraterrestrial intelligence.*

*Astronomers soon found that a rapidly rotating neutron star could produce such signals and the next year a pulsar was discovered in the Crab Nebula. This was the star observed exploding in 1054 by Chinese astronomers and others. It reached the brightness of Venus and was visible in daylight for more than 23 days.*

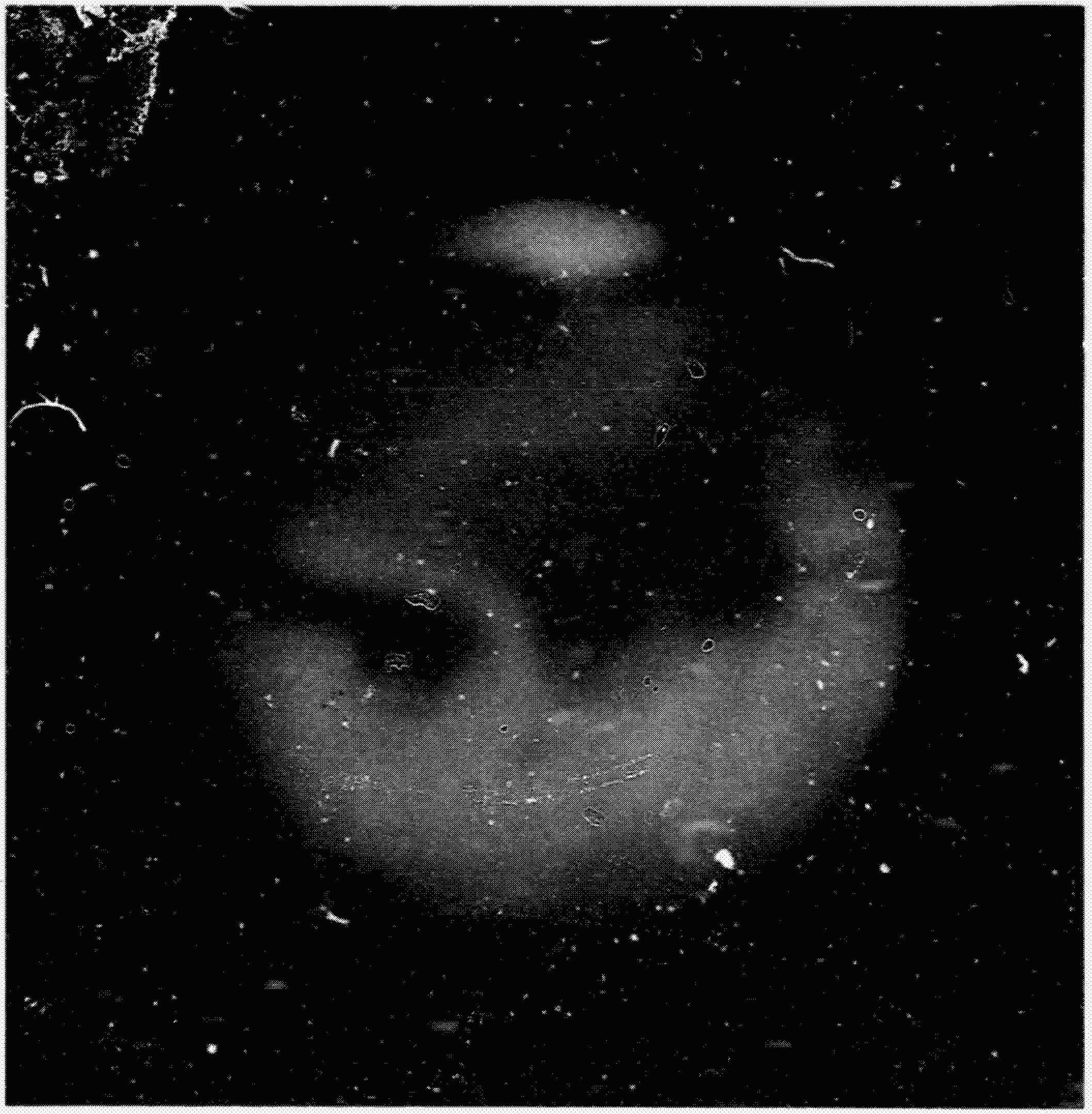
*Most pulsars have periods ranging from a 30th of a second to about three minutes. Some 100 pulsars have been discovered, most of them located in our galaxy, some 300 to 30,000 light years from the Sun. With the exception of the Crab Nebula pulsar, they are apparently millions of years old.*

**A "BLACK HOLE"** *(artist's concept shown here) represents an astronomical phenomenon about which today's astronomers theorize as a means of describing certain gravitational anomalies in our universe. The gravitational forces in these black holes are considered to be so extreme that no radiation, not even visible light, can escape. According to widely held present theories, a very large star could explode, blowing away its outer shell of gases and lighter elements. Heavier elements in its core then collapse upon themselves. This implosion is envisioned as creating exceptionally dense materials and gravitational forces that continue to sweep up other matter in the vicinity of a growing black hole.*

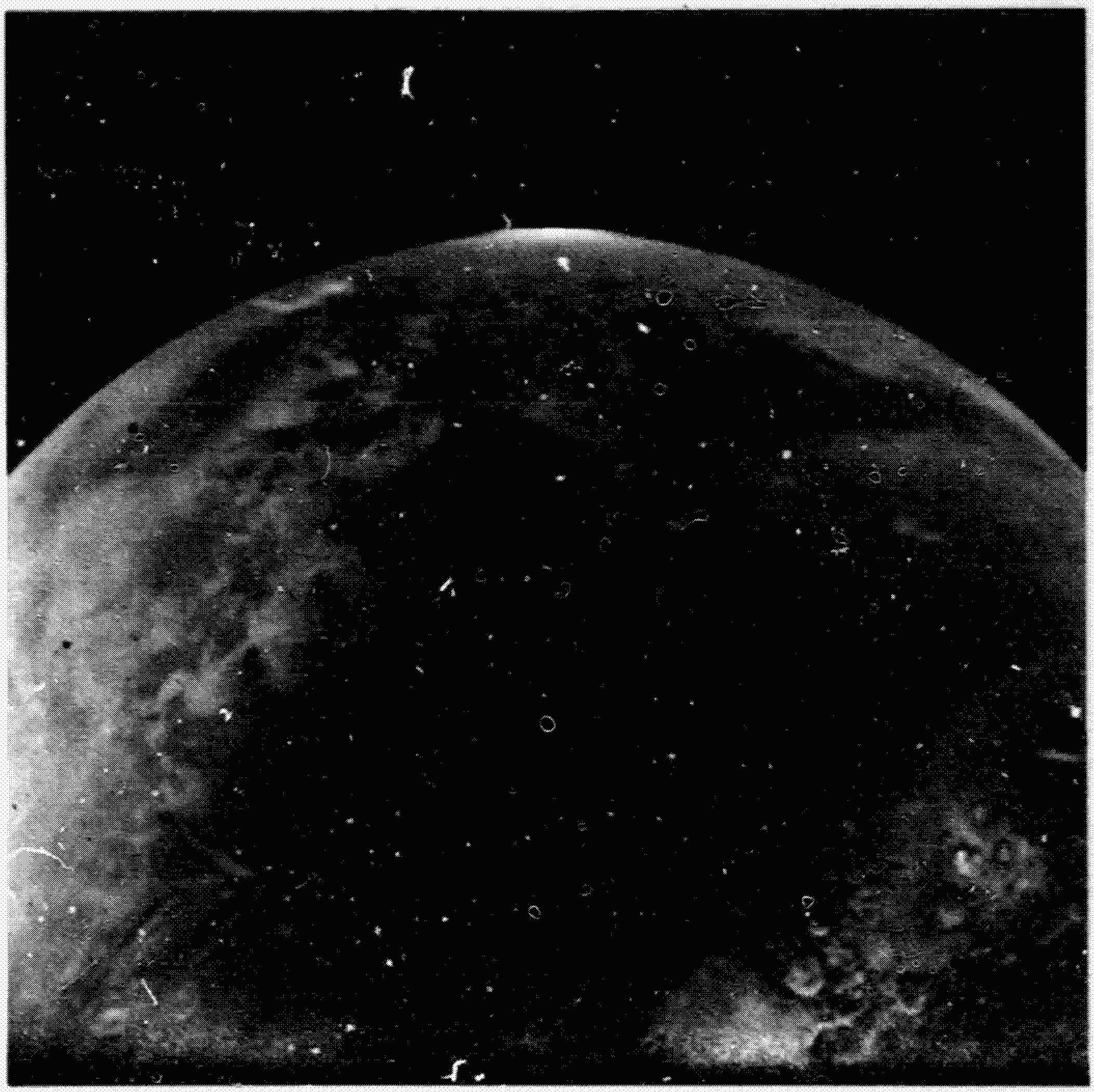


**THIS IS THE TYPE OF RESOLUTION** *(taken in the ultraviolet) of Venus that will be obtained by Space Telescope from its Earth orbit. The photo was taken by Mariner 10 in 1974 as it flew by the planet enroute to Mercury. The spacecraft was 720,000 kilometers (450,000 miles) away from Venus when the television cameras took the picture.*

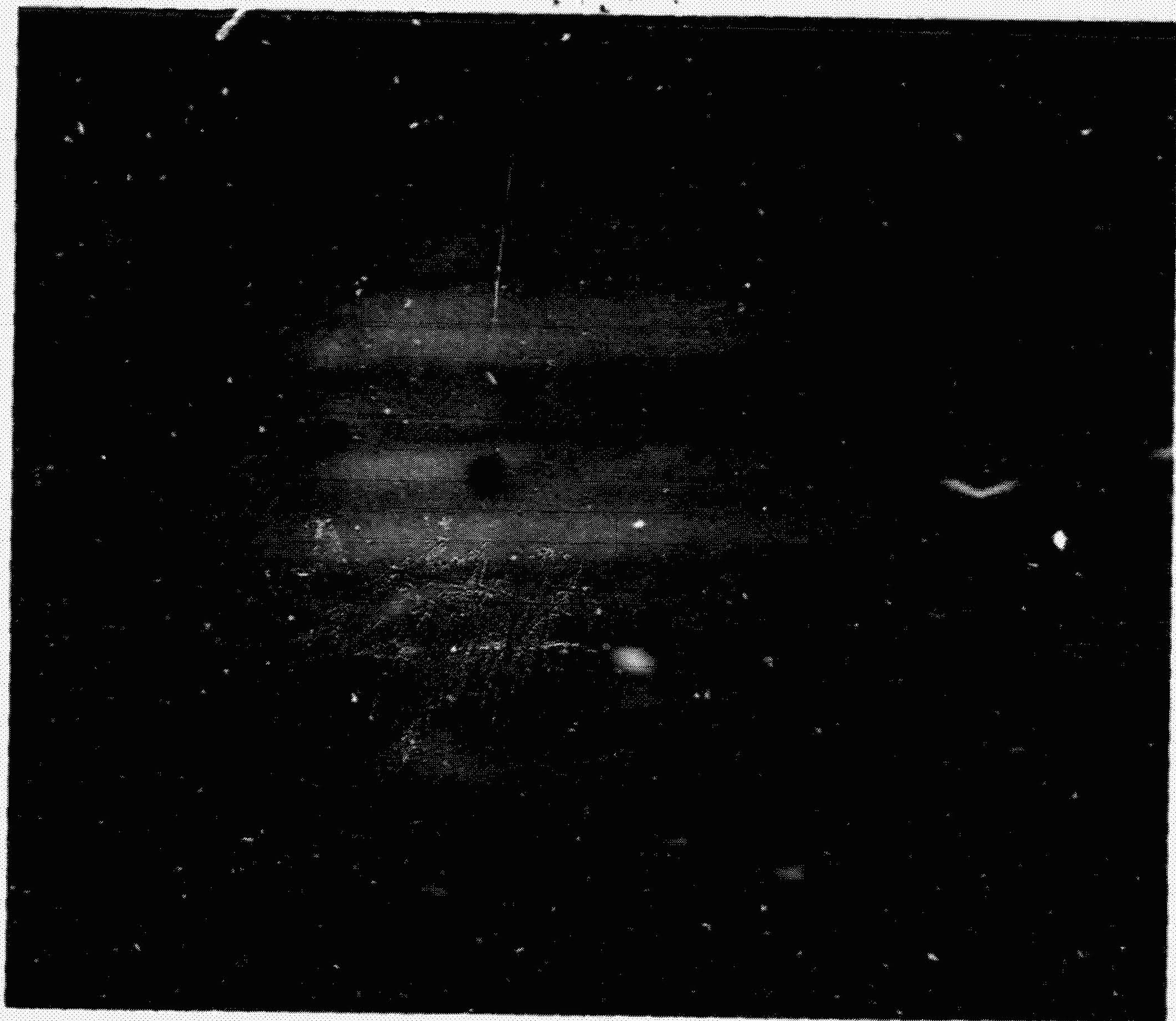
*We will be able to view Venus only in its crescent stage because of sun angle constraints on the Space Telescope. It can only look at the planet when it is at its maximum angular separation from the Sun. This same constraint completely precludes any observation of Mercury because it is too close to the Sun.*



**VIEW OF MARS** *from a ground-based observatory.*

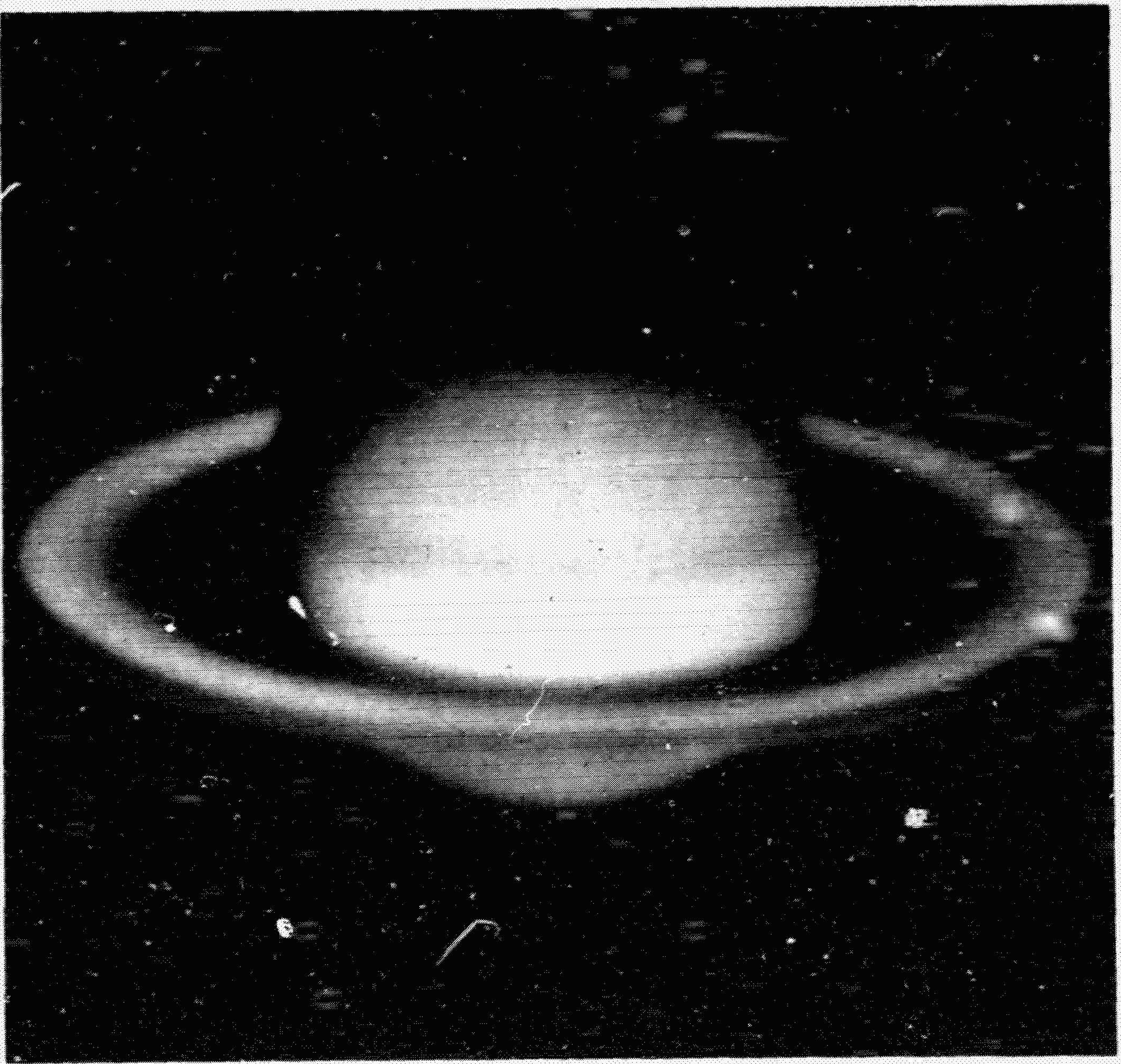


**THIS PICTURE OF MARS** *is similar to the resolution that will be achieved by Space Telescope. It was made from three frames taken nine seconds apart by the Viking Orbiter circling the planet, in June 1976.*

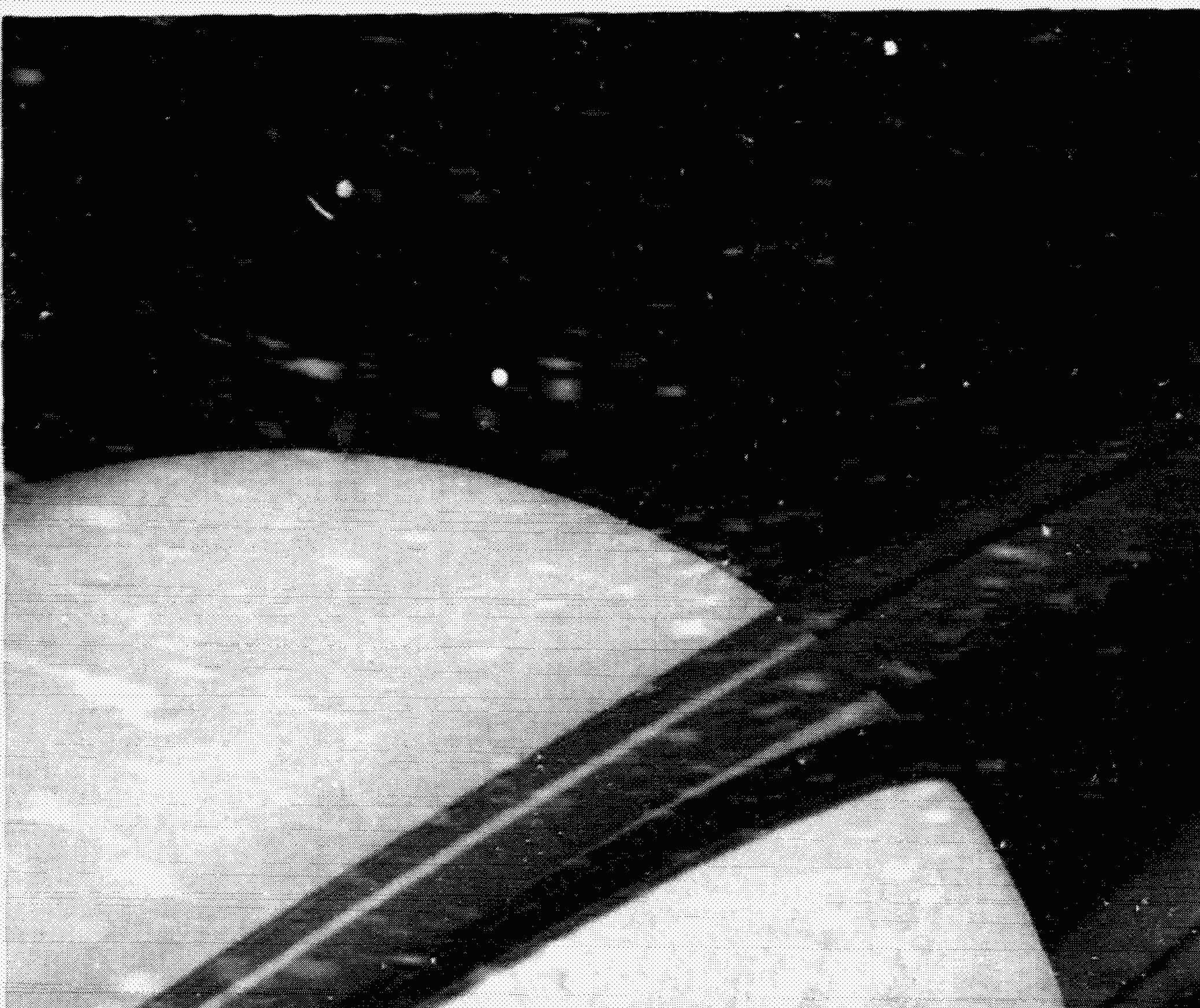


**TWO VIEWS OF JUPITER:** *On the left is a very good ground-based photo. On the right is a picture taken of Jupiter obtained by the Voyager spacecraft in 1979. Space Telescope will view Jupiter at a similar resolution. However, instead of being limited as Voyager was to only a portion of the planet at this resolution, the Space Telescope will be able to view the entire disk with similar clarity and detail.*

*The ground-based photo (left) of Jupiter will be similar in resolution to pictures Space Telescope will obtain of the planets Uranus and Neptune. The best observatories on Earth can obtain photos of the two planets showing no more than tiny disks with almost no detail.*



**TWO VIEWS OF SATURN:** *At the left is a typical ground-based photo. At the right is the type of resolution Space Telescope will make available. The instrument will be able to return photos of the entire planet at this resolution. The picture shows Saturn and two of its moons, Tethys (above) and Dione taken by Voyager I in November 1980 from 13 million kilometers (8 million miles) away.*



**RANUS,** *an extremely faint point of light to viewers from Earth telescopes, is tilted so far over on its axis that its axis is nearly perpendicular to the plane of the elliptic in which it orbits. It has at least five very dark rings, first identified by a high-flying NASA observatory. These rings are believed to be made up of rock similar to a type found in certain meteors.*

**NEPTUNE** *has a hydrogen-rich atmosphere. Methane gas in that atmosphere absorbs light from the Sun causing it to appear as a featureless blue planet. As seen from Earth it is only a dot on a photographic plate. Neptune has two moons.*

**PLUTO** *is not a gaseous planet but is covered by frozen methane, probably concealing a rocky interior. Since there are no deep space missions planned to observe Pluto, a mere pinprick of light in ground-based telescope photos, the planned orbiting instrument is the only device offering any early prospect of studying the planet in more detail. Pluto has a newly-discovered moon which is difficult to see from Earth. Space Telescope should enable astronomers to study this moon's orbit and, perhaps, other physical characteristics.*

# Space Telescope Responsibilities

*NASA's* Office of Space Science and Applications, Headquarters, Washington, D.C., is responsible for overall direction of the Space Telescope program.

Marshall Space Flight Center, Huntsville, Ala., has project management responsibility to direct the building of the spacecraft and for the proper integration of all its components to assure efficient operation in space.

Goddard Space Flight Center, Greenbelt, Md., is responsible for scientific instrumentation, mission operations, and data reduction. It is also responsible for monitoring the activities of the Telescope Science Institute.

The Johnson Space Center, Houston, Tex., has Space Shuttle and flight crew operations management responsibility and will work with all participants in the project to assure maximum technical and scientific results.

Kennedy Space Center, Fla., has Space Shuttle launch operations responsibility and will supervise all aspects of the launch phase.

The European Space Agency provides the Faint Object Camera as well as the solar arrays and will participate in flight operations aspects of the mission.

## Two Principal Contractors

There are two prime contractors for the Space Telescope. Lockheed Missiles and Space Company, Sunnyvale, Cal., is responsible for design, development and building of the Support Systems Module as well as the integration and verification of other major elements into the flight spacecraft.

Perkin-Elmer Corporation, Danbury, Conn., has responsibility for development of the Optical Telescope Assembly.

## NASA's Role

NASA has selected 45 scientists to participate in the design and early operational phases of the project.

Program Manager for Space Telescope is Marc Bensimon, Program Engineer is Arthur J. Reetz, and Program Scientist is Dr. Edward J. Weiler, all from NASA Headquarters. Dr. Fred A. Speer is Project Manager, Jean Olivier is Project Engineer, and Dr. C.R. O'Dell is Project Scientist, all of Marshall Space Flight Center.

Gerald Burdett is Manager of the Space Telescope Science and Operations Office and Dr. David S. Leckrone is Space Telescope Scientific Instruments Scientist, both of Goddard Space Flight Center.

## ESA's Role

The European Space Agency (ESA), by agreement with NASA, is responsible for furnishing the solar arrays, for delivery of one of the scientific instruments, the Faint Object Camera, and for staffing the Space Telescope Science Institute with a number of European scientists.

# Space Telescope Science Working Group

| *Scientist* | *Institution* | *Responsibility* |
|---|---|---|
| John N. Bahcall | Institute for Advanced Study, Princeton, New Jersey | Interdisciplinary Scientist |
| Robert C. Bless | University of Wisconsin | Principal Investigator—High Speed Photometer |
| John C. Brandt | Goddard Space Flight Center | Principal Investigator—High Resolution Spectrograph |
| John J. Caldwell | State University of New York, Stony Brook | Interdisciplinary Scientist |
| William G. Fastie | The Johns Hopkins University | Telescope Scientist |
| Edward J. Groth | Princeton University | Data and Operations Team Leader |
| Richard J. Harms | University of California, San Diego | Principal Investigator—Faint Object Spectrograph |
| William H. Jefferys | University of Texas, Austin | Astrometry Science Team Leader |
| David L. Lambert | University of Texas, Austin | Interdisciplinary Scientist |
| David S. Leckrone | Goddard Space Flight Center | Scientific Instruments Scientist |
| Malcolm S. Longair | The Royal Observatory, Edinburgh, Scotland | Interdisciplinary Scientist |
| F. Duccio Macchetto | European Space Agency, Noordwijk, The Netherlands | Faint Object Camera Project Scientist |
| C.R. O'Dell | Marshall Space Flight Center | Project Scientist |
| Nancy G. Roman | NASA Headquarters | Program Scientist (retired) |
| Daniel J. Schroeder | Beloit College, Beloit, Wisconsin | Telescope Scientist |
| H.C. van de Hulst | Huygens Laboratory, Leiden, The Netherlands | Faint Object Camera Science Team Leader |
| Edward J. Weiler | NASA Headquarters | Program Scientist |
| James A. Westphal | California Institute of Technology | Principal Investigator—Wide Field/Planetary Camera |

## *Credits and Acknowledgments*

Acknowledgements: Material for this book came from numerous scientific publications and interviews. I am particularly indebted to the following persons involved in the Space Telescope program for interviews and for furnishing research material: Dr. Edward J. Weiler, Program Scientist, Headquarters, Washington, D.C.; Arthur J. Reetz, Space Telescope Program Engineer, Headquarters, Washington, D.C.; Dr. C.R. O'Dell, Project Scientist, Marshall Space Flight Center, Huntsville, Ala.; Dr. Fred A. Speer, Space Telescope Project Manager, Marshall; Jean Olivier, Space Telescope Project Engineer, Marshall; Don Worrell, Public Affairs Office, Marshall; Dr. David S. Leckrone, Space Telescope Scientific Instruments Scientist, Goddard Space Flight Center, Greenbelt, Md.; and Dr. G. Edward Danielson, Wide Field Planetary Camera, Jet Propulsion Laboratory, Pasadena, Cal. — J.J.M.

## *About the Author*

Joseph J. McRoberts, Alexandria, Va., is a science writer, graduated from the University of Missouri School of Journalism, Columbia, Mo. He has been a reporter for the Illinois State Journal, Springfield, Ill., a newsman for the Columbia Broadcasting System, WBBM, Chicago, and, from 1962 to 1980, served the Public Affairs Offices of NASA Headquarters and Goddard Space Flight Center in various capacities, including Public Affairs Officer at Headquarters and News Chief at Goddard Space Flight Center.